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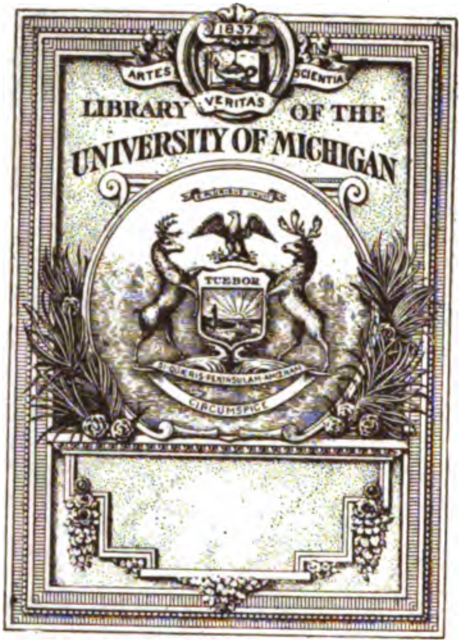
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NEUROLOGY

QUAIN'S

ELEMENTS OF ANATOMY

ELEVENTH EDITION. IN FOUR VOLUMES ROYAL 8vo.

Edited by EDWARD ALBERT SCHÄFER, F.R.S.
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QUAIN'S
ELEMENTS OF ANATOMY

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IN FOUR VOLUMES

VOL. III.

NEUROLOGY

By E. A. SCHÄFER and J. SYMINGTON

PART II.

CONTAINING THE DESCRIPTIVE ANATOMY OF THE PERIPHERAL NERVES AND OF THE ORGANS OF SPECIAL SENSE

WITH ONE PLATE AND NUMEROUS ILLUSTRATIONS
MANY OF WHICH ARE COLOURED

ELEVENTH EDITION

LONGMANS, GREEN, AND CO.
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1909

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PREFACE TO VOLUME III

THE third volume of Quain's Anatomy (Eleventh Edition) is devoted to the description of the Structure of the Nervous System, including the Organs of Special Sense. The macroscopic anatomy has been undertaken by Professor Symington, the microscopic anatomy by Professor Schäfer. The volume has been issued in two parts, the first of which, including the general structure and mode of development of the elements of the nervous system, and the structure of the central nervous system, appeared in September 1908; the second, dealing with the peripheral nervous system and sense organs, in September 1909. A considerable portion of the work has been rewritten, and a large number of the illustrations are new, many having been prepared expressly for this edition. Others are due to the courtesy of various authors and publishers, who have given permission for the reproduction of illustrations from books and journals written or published by them. The authorship of each is indicated under its title, but the Editors desire especially to acknowledge their indebtedness to Professor Ramón Cajal, who was good enough to lend many of his original drawings for reproduction in this book, and whose work on the Structure of the Nervous System has been consulted throughout in the account of the microscopic structure of the brain and cord. Special acknowledgment is also due to the text-books of Edinger, van Gehuchten, and Llewellys Barker, to the important monographs on the Brain and on the Organ of Hearing by Professor G. Retzius, to various articles in the 'Biological Investigations' of the same author, and to the articles by Leber, H. Virchow, Greeff, and others, in the second edition of Graefe-Saemisch 'Handbuch der Augenheilkunde.' The Editors have to thank Dr. Lindsay Johnson for permission to reproduce the coloured plate showing the ophthalmoscopic appearance of the retina which is inserted opposite page 226, and Mr. L. Laurance for the use of the block of fig. 162.

Most of the new figures illustrating the macroscopic anatomy of the brain and sense organs have been drawn by Mr. S. A. Sewell; those illustrating the microscopic anatomy have been drawn or photographed by Mr. Richard Muir.

The index has been prepared by Dr. T. W. P. Lawrence.

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THE NERVES.

In this section is comprised the descriptive anatomy of the cerebrospinal and sympathetic nerves, and their ganglia. The peripheral division of the nervous system also includes the organs of the external senses, which will be described after the Nerves.

The separation of the sympathetic from the cerebrospinal nerves is convenient for purposes of description, but does not indicate a difference of origin or an anatomical independence of the two systems, since the fibres composing the sympathetic are connected centrally, either directly or indirectly, with the cerebrospinal axis, which they leave as constituents of the roots of certain of the cerebrospinal nerves. Moreover, the division cannot in all cases be strictly maintained, for some of the ganglia (ciliary, sphenopalatine, otic, and submaxillary), which are described in connexion with the cerebral nerves to which they are attached, have a close affinity with those of the sympathetic system, while on the other hand many of the terminal plexuses distributed to the viscera, and generally regarded as parts of the sympathetic system, are composed in large part of fibres which pass into them directly from cerebrospinal nerves without traversing the cord of the sympathetic.

THE CEREBROSPINAL NERVES.

The nerves attached directly to the great cerebrospinal centre constitute a series of symmetrical pairs, of which twelve issue from the cranium through different apertures in its base, and are thence named *cerebral* or *cranial*. The next following nerve passes out between the occipital bone and the atlas, and the remaining thirty nerves all issue below the successive segments of the vertebral column. The first is sometimes distinguished by the name of *suboccipital*, but to the whole series of thirty-one nerves the name of *spinal* will be here given.

CEREBRAL NERVES.

The cerebral nerves (*nervi cerebrales*), besides being distinguished by numbers in the order of their passage through the dura mater lining the cranium, have likewise received other names, according to the place or mode of their distribution, or their functions.

The number of the cerebral nerves is now universally stated as twelve, following the enumeration which was proposed by Sœmmering in 1778. Willis (1664) reckoned these as nine pairs, of which the facial and acoustic together composed the seventh pair, while the glossopharyngeal, vagus, and accessory were included in the eighth. Willis also looked upon the suboccipital as a cerebral nerve, and thus counted ten pairs. The two arrangements, as well as the special designations of the several nerves, as given in the Basel 'Nomina Anatomica,' are shown in the following table:

WILLIS.	SŒMMERING.	B. N. A.
First pair of nerves	First pair of nerves	Nervus olfactorius.
Second „	Second „	„ opticus.
Third „	Third „	„ oculomotorius.
Fourth „	Fourth „	„ trochlearis.
Fifth „	Fifth „	„ trigeminus.
Sixth „	Sixth „	„ abducens.
Seventh „ portio dura	Seventh „	„ facialis.
portio mollis	Eighth „	„ acusticus.
Eighth „ n. vagus	Ninth „	„ glossopharyngeus.
	Tenth „	„ vagus.
n. accessorius	Eleventh „	„ accessorius.
Ninth „	Twelfth „	„ hypoglossus.
Tenth „	First cervical	

Connexion with the cerebrospinal axis.—The place at which a cerebral nerve is attached to the surface of the cerebrospinal axis is usually termed the *superficial origin* of the nerve.

The superficial attachments of the cerebral nerves are quite obvious: the filaments of the first pair to the olfactory lobes of the cerebral hemispheres; the second pair to the thalami and the dorsal part of the mesencephalon; the third to the pedunculi cerebri or ventral part of the mesencephalon; the fourth to the superior medullary velum; the fifth to the pons; and the remainder to the medulla oblongata, with the exception of the greater part of the eleventh pair, which is connected with the cervical portion of the spinal cord.

The cerebral nerves consist of one or more *components*, according to whether they are composed entirely of fibres with a similar origin and distribution, or contain fibres which differ in these respects. These components are either *efferent* or *afferent*. The efferent nerve-components consist of fibres which are outgrowths of nerve-cells situated in the grey matter, while the afferent components originate in cells forming ganglia on the nerves outside the brain. The efferent nerves are usually motor, and the cells from which they arise constitute their nuclei of origin (*motor nuclei*). The afferent fibres are usually sensory, and the ganglionic cells with which they are connected have peripheral processes passing to a sensory surface, or sense-organ, and central processes which pass into the brain and end in branches around nerve-cells which form the *terminal sensory nuclei*.

The course of the fibres within the cerebrospinal axis, and their connexion with the nerve-nuclei are in some cases difficult to follow, and in many respects are as yet but imperfectly understood. They have been fully discussed in the accounts of the parts of the spinal cord and brain in which they occur, and to these reference may be made for further details than are given in the following descriptions.

Mode of exit from the cranium.—Each of the cerebral nerves, after traversing the subarachnoid space, receives a sheath from the arachnoid, and then enters an aperture in the dura mater (in the case of the third, fourth, fifth, and sixth nerves at some distance from the osseous foramina by which they emerge), and carries with it in its passage from the cranial cavity a tubular prolongation of that membrane. Some of these nerves, or their main divisions, are contained in distinct foramina of the cranium, others are grouped together in one foramen and may be invested in a common sheath by the arachnoid and by the dura mater. The numerous small olfactory nerves pass from the nose through the cribriform plate of the ethmoid bone; the optic nerve pierces the base of the small wing of the sphenoid bone; the third, fourth, and sixth nerves, with the ophthalmic division of the fifth, pass through the sphenoidal fissure; the maxillary and mandibular divisions of the fifth pass respectively through the foramen rotundum and foramen ovale of the great wing of the sphenoid; the facial and acoustic nerves traverse the internal auditory meatus of the petrous bone; the glossopharyngeal, vagus, and accessory nerves pass through the middle compartment of the jugular foramen between the petrous and occipital bones; and the hypoglossal nerve emerges through the anterior condylar foramen of the occipital bone.

General distribution.—The greater number of the cerebral nerves are entirely confined in their distribution within the limits of the head, as in the case of the first six pairs, the acoustic, glossopharyngeal, and hypoglossal nerves. Of these, the olfactory, optic, and acoustic are restricted to their respective organs of sense; while the third, fourth, and sixth are exclusively motor nerves in connexion with the muscles of the eyeball and the elevator of the upper eyelid. In the fifth or trigeminal nerve all the fibres derived from the large root, and connected with the semilunar ganglion, are entirely sensory in their function, and constitute the whole of the first and second and the greater part of the third division of the nerve; but the last of these divisions has associated with it the fibres of the small or motor root, so as to become in some degree a compound nerve. As a nerve of sensation the trigeminal occupies in its distribution the greater part of the head superficially and deeply, excepting that part of the scalp which is situated behind a perpendicular line passing through the external auditory meatus. The muscular distribution of the third division of the fifth nerve is chiefly to the muscles of mastication. The glossopharyngeal is also a mixed nerve, and is distributed to the tongue, pharynx, and part of the ear-passages; while the hypoglossal is purely a motor nerve, destined for the muscles of the tongue, its so-called 'descending' and other branches, which supply in part the muscles connected with the hyoid bone, being composed of fibres derived from the upper spinal nerves.

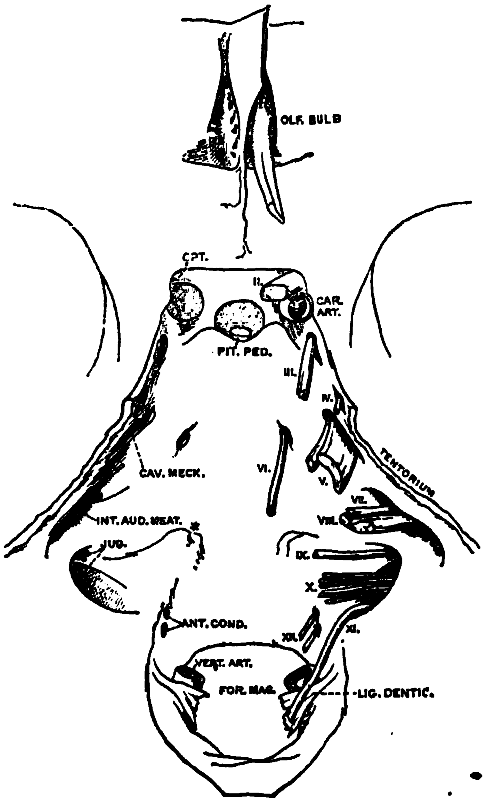


FIG. 1. — SKETCH OF THE MIDDLE PORTION OF THE BASE OF THE SKULL, SHOWING THE ENTRANCE OF THE CEREBRAL NERVES INTO THE DURA MATER. (Drawn by T. W. P. Lawrence.)

The tentorium has been divided close to its attachment to the upper border of the petrous. On the right side the nerves are in place; on the left side they have been removed, and the apertures in the dura mater are seen.

Of the remaining nerves, one, the facial, mainly motor in function, is almost entirely cephalic in its distribution, giving fibres to all the superficial and a few of the deeper muscles of the head; but one branch passes downwards in the neck to the platysma myoides. Its sensory root possesses a ganglion (geniculate), and supplies part of the mucous membrane of the palate and tongue.

A

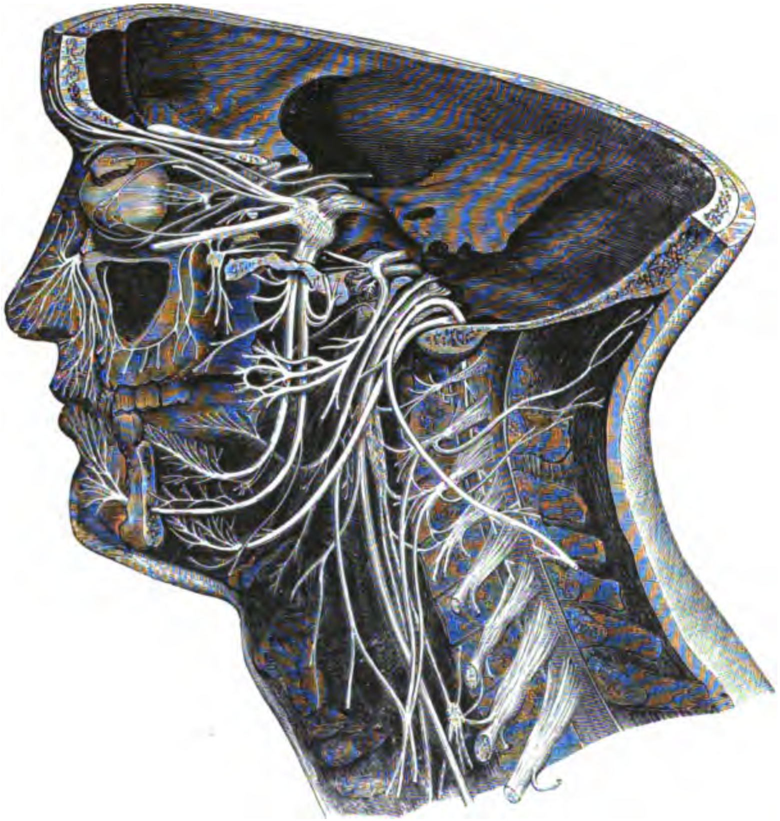
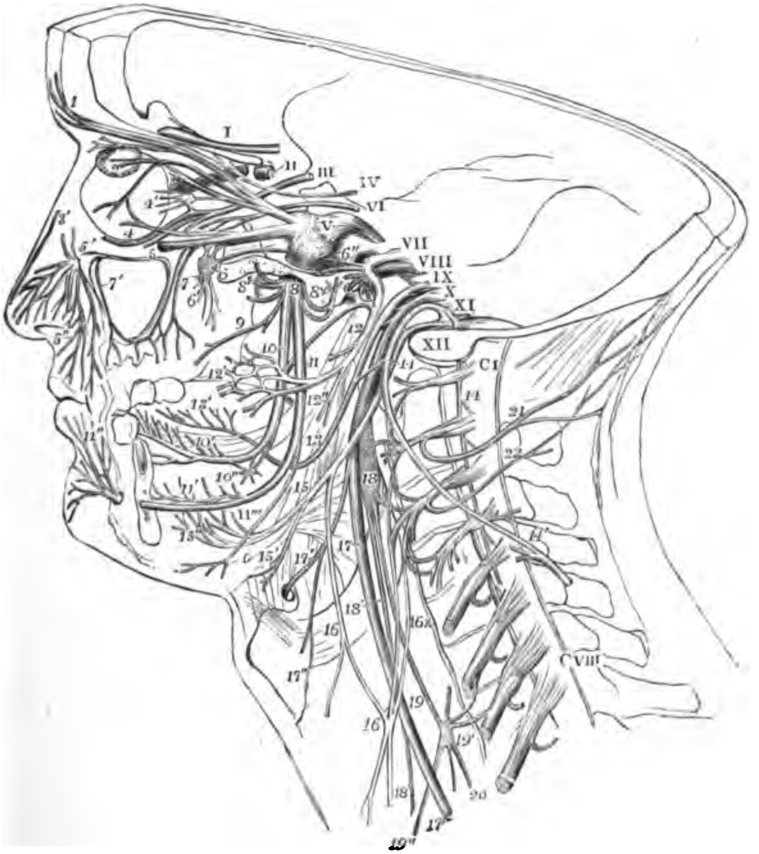


FIG. 2.—A. SEMIDIAGRAMMATIC VIEW OF A DEEP DISSECTION OF THE CEREBRAL NERVES ON THE LEFT SIDE OF THE HEAD. B. EXPLANATORY OUTLINE OF THE SAME. (Allen Thomson.) ½.

The Roman numerals from I to XII indicate the roots of the several cerebral nerves as they lie in or near their foramina of exit; V, is upon the large root of the fifth with the semilunar ganglion in front; C I, the suboccipital or first cervical nerve; C VIII, the eighth. The branches of the nerves are marked as follows—viz. 1, supra-orbital branch of the fifth; 2, lacrymal passing into the gland; 3, naso-ciliary passing towards the anterior internal orbital canal, and giving the long root to the ciliary ganglion, 4′; 3′, termination of the naso-ciliary nerve; 4, lower branch of the third nerve; 5, maxillary division of the fifth passing into the infra-orbital canal; 5′, the same issuing at the infra-orbital foramen and being distributed as inferior palpebral, lateral nasal, and superior labial nerves, 5″; 6, ganglion of Meckel and Vidian nerve joining it; 6′, palatine and other nerves descending from it; 6″, large superficial petrosal nerve; 7, posterior dental nerves; 7′, placed in the maxillary antrum, which has been opened, points to the anterior dental nerve; 8, mandibular division of the fifth immediately below the foramen ovale; 8′, some of the muscular branches coming from it; 8 ×, the auriculo-temporal branch cut short, and above it the small superficial petrosal nerve connected with the facial; 9, buccal and external pterygoid; 10, lingual nerve; 10′, its distribution to the side and front of the tongue and to the sublingual gland; 10″, submaxillary ganglion; below 10, the chorda tympani passing forwards

Lastly, the tenth or vagus and the eleventh or accessory nerves differ from the foregoing in having only a very limited distribution in the head, and in furnishing nerves in much greater proportion to organs situated in the neck and trunk. The first of these, after giving a small branch to the external ear, and supplying nerves to the pharynx and larynx, the trachea, gullet, lungs, and heart, extends into the abdominal cavity as the principal nerve of the stômach. The other, the accessory, which is classed with the cerebral nerves in consequence of its passing out through one of the foramina of the skull, is entirely a motor nerve; it is partially united with the vagus near its origin, and thus furnishes

B



from the facial above 12, to join the lingual nerve; 11, inferior dental nerve; 11', the same nerve and part of its dental distribution exposed by removal of the jaw; 11", its termination as the mental nerve; 11'", its mylohyoid branch; 12, twigs of the facial nerve immediately after its exit from the stylomastoid foramen to the posterior belly of the digastric and to the stylohyoid muscle; 12', temporo-facial division of the facial; 12", cervico-facial division; 13, trunk of the glossopharyngeal passing round the stylopharyngeus muscle after giving pharyngeal and muscular branches; 13', its distribution on the side and back part of the tongue; 14, accessory nerve; 14', the same after having passed through the sternomastoid muscle uniting with branches from the cervical nerves; 15, hypoglossal nerve; 15', its twig to the thyrohyoid muscle; 15", its distribution to the muscles of the tongue; 16, the descending cervical nerve giving a direct offset to the anterior belly of the omohyoid muscle, and receiving the communicating branches 16 × from the cervical nerves; 17, vagus nerve; 17', its superior laryngeal branch; 17", external laryngeal twig; 18, superior cervical ganglion of the sympathetic, uniting with the upper cervical nerves, and giving at 18' the superficial cardiac nerve; 19, the trunk of the sympathetic; 19', the middle cervical ganglion, uniting with some of the cervical nerves, and giving 19", the large or middle cardiac nerve; 20, continuation of the sympathetic down the neck; 21, great occipital nerve; 22, third occipital.

some of the motor fibres of that nerve, but it is mainly distributed in the sternomastoid and trapezius muscles.

Fig. 2 (A and B) is introduced in illustration of the general view of the distribution above given. In this figure the cranium and orbit have been opened up to the depth of the several foramina through which the nerves pass. The greater part of the lower jaw has also been removed on the left side, and the tongue, pharynx, and larynx are partially in view. The occipital bone has been divided by an incision passing down from the occipital protuberance and through the condyle to the left of the foramen magnum. The cervical vertebræ have been divided to the left of the middle line, and the sheath of the spinal cord opened so as to expose the roots of the cervical nerves.

FIRST OR OLFACTORY NERVE.

The **olfactory** differs from the other cerebral nerves in arising from nerve-cells (olfactory) situated in the surface epithelium, in its fibres being non-medullated and entering the cranial cavity by numerous foramina. The olfactory cells represent morphologically the ganglionic cells on the sensory roots of the spinal nerves which have retained the primitive position of such sensory cells in the surface epithelium. The cells are bipolar, with one process passing to the surface between the columnar cells of the olfactory mucous membrane, and the other forming the olfactory nerve proper. They form an *inner group* situated over the upper third of the vertical plate of the ethmoid, and an *outer group* on the mesial surface of the lateral mass of the ethmoid nearly as far down as the lower edge of the superior turbinate process. The bundles of the olfactory nerve are usually described as communicating freely with one another as they ascend, thus giving rise to a narrow-meshed plexus beneath the mucous membrane; but according to E. A. Read [1] the bundles do not anastomose, the appearance of anastomosis being due to the crossing of the nerve-bundles and to the net-like arrangement of the connective tissue and blood-vessels. The fibres are lodged for a short distance in grooves on the ethmoid before they pierce the cribriform plate in about twenty bundles. Immediately above this plate they enter the olfactory bulb, and end in the so-called olfactory glomeruli, where they form synapses with processes from the mitral cells of the bulb.

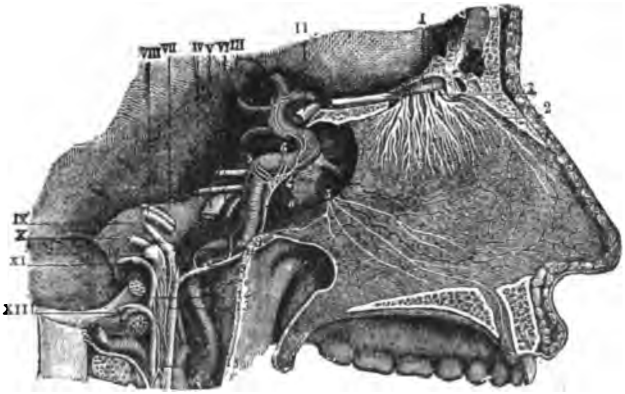


FIG. 3.—DISTRIBUTION OF THE OLFACTORY NERVES ON THE SEPTUM OF THE NOSE. (From Sappey, after Hirschfeld and Leveillé.) ⅔.

The septum is exposed and the anterior palatine canal opened on the right side. I, points to the olfactory bulb, and the remaining Roman numbers to the several cerebral nerves; 1, the olfactory nerves as they pass through the cribriform plate; 2, internal twig of the naso-ciliary branch of the ophthalmic nerve; 3, naso-palatine nerve.

SECOND OR OPTIC NERVE.

The **optic nerve** is composed mainly of the axons of the ganglionic cells of the retina. As these cells do not constitute the primary, but probably the tertiary, cellular elements of the visual tract, the optic nerve is not homologous with any of the other cerebrospinal nerves, and corresponds rather to a tract of fibres within the brain, being indeed a part of the central nervous system. The axons or central processes of the ganglionic cells pass through the nerve-fibre layer of the retina and converge to the optic disc, where they perforate the choroid and sclerotic coats of the eyeball and then pass backwards and inwards as the *optic nerve* to the *optic commissure.* Here they partially decussate with the fibres of the opposite nerve and are continued as the *optic tract* to the brain.

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[1] American Journal of Anatomy, viii. 1908.

The optic nerve proper lies in the orbit, the optic foramen, and the cranial cavity. Its total length is from 30 to 40 mm.; it has a diameter of 3 to 4 mm. While in the orbit and optic foramen it is invested by two sheaths, an outer from the dura mater and an inner from the arachnoid, which are attached in front to the eyeball. After piercing the choroid and sclerotic it leaves the eyeball on its posterior aspect about 3 mm. internal to its centre, and passes backwards and inwards between the recti muscles, but separated from them by fat. Its intra-orbital part measures from 20 to 30 mm., and has a slightly flexuous course, its length exceeding the distance in a straight line from the optic foramen to the eyeball by about 5 mm., so as to allow of the movements of the latter. It is surrounded by the ciliary vessels and nerves, has the ciliary ganglion on its outer side, and is pierced on its mesial and lower quadrant about 10 mm. behind the eyeball by the central artery of the retina, which, with a companion vein, runs in the axis of the nerve to the eyeball.

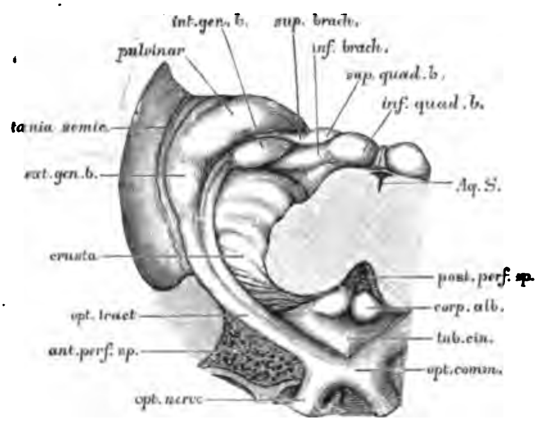

FIG. 4.—ORIGIN AND RELATIONS OF THE OPTIC TRACT. (G. D. Thane.)

The mid-brain has been divided immediately above the pons, and the part is viewed from below

As the nerve lies in the optic foramen it has the ophthalmic artery below and to its outer side; on its inner side the optic nerve is separated from the sphenoid and posterior end of the ethmoidal cells by a thin plate of bone. From the optic foramen the nerve passes upwards, inwards, and backwards to the optic commissure. The length of this intracranial portion of the optic nerve varies from 4 to 16 mm., the average being about 10 mm. Its upper surface comes into close relation with the posterior part of the gyrus rectus and usually grooves it. The internal carotid artery lies against the lower and outer part of the nerve, close to the optic foramen, and the anterior cerebral artery crosses inwards above the nerve near its junction with the chiasma.

The **optic commissure** or **chiasma** is of an oblong form, the longer diameter (13 mm.) being directed transversely. It is placed some distance above and behind the so-called optic groove of the sphenoid bone[1] and forms a prominence in the floor of the third ventricle. The internal carotid artery, ascending to the brain, is close to its outer side, and the anterior cerebral branch passes in front of it to reach the longitudinal fissure. A large number of the fibres of the two nerves decussate in the commissure, but some are continued from the nerve to the tract of the same side, while those fibres of the tract which are connected with the mesial geniculate body do not pass into either optic nerve, but cross in the hinder part of the chiasma to the opposite tract, constituting the *inferior commissure* of Gudden (see Vol. III. Part I. p. 240).

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[1] T. W. P. Lawrence, Proc. Anat. Soc. May 1904; Journ. Anat. and Phys. xxviii.; and R. Zander, Anat. Anzeiger, xii.

The **optic tract** forms a rounded bundle which courses backwards and outwards between the tuber cinereum and the anterior perforated spot to the cerebral peduncle. Here it becomes flattened and closely adherent to the peduncle as it crosses the upper part of its lateral surface, and divides into a mesial and a lateral root. The mesial root appears to end in the mesial geniculate body, but actually passes beneath it, and the lateral root can be traced to the lateral geniculate body, the pulvinar of the thalamus, and by its brachium to the superior quadrigeminal body.

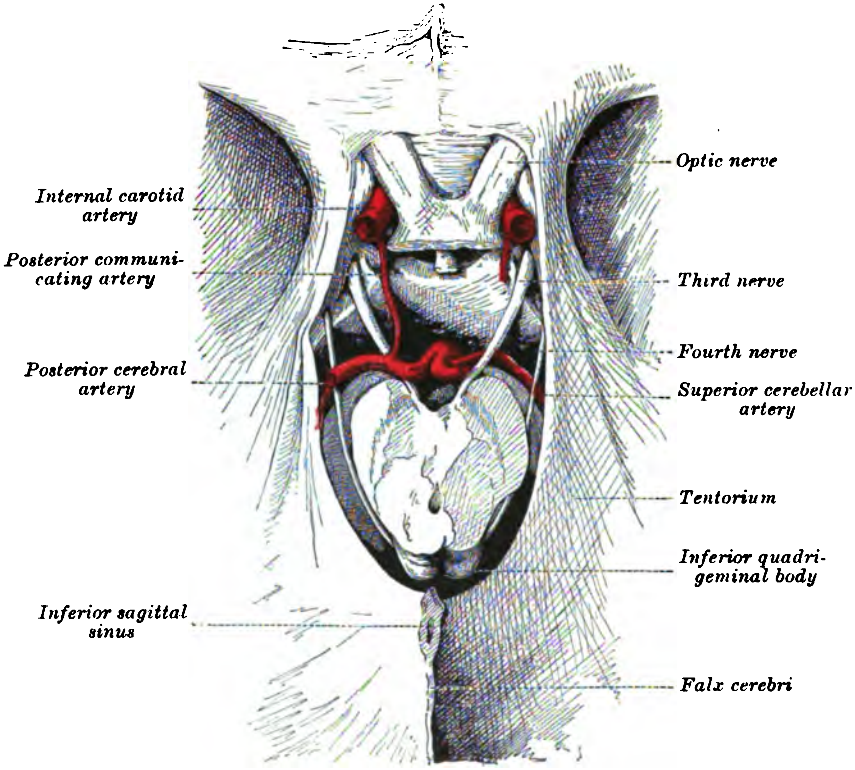
Internal carotid artery
Posterior communicating artery
Posterior cerebral artery
Inferior sagittal sinus
Optic nerve
Third nerve
Fourth nerve
Superior cerebellar artery
Tentorium
Inferior quadrigeminal body
Falx cerebri

FIG. 5.—THE THIRD AND FOURTH NERVES IN THEIR INTRACRANIAL COURSE.
(G. D. Thane, drawn by T. W. P. Lawrence.)

The mid-brain is divided in the aperture of the tentorium, and the cerebrum removed. On the right side the posterior cerebral and posterior communicating arteries are cut short in order to expose the origin of the third nerve. On the left side the tentorium and pedunculus cerebri are slightly separated so as to show the fourth nerve more fully.

THIRD OR OCULOMOTOR NERVE.

The **third nerve** (*oculomotorius*), the common motor nerve of the eyeball, gives branches to all the muscles of the orbit, with the exception of the superior oblique and external rectus. It also supplies, through its connexion with the ciliary ganglion, the sphincter muscle of the iris and the ciliary muscle of the eyeball.

The fibres of the nerve spring from the oculomotor nucleus (mainly from that of the same side) in the grey matter of the floor of the aqueduct of Sylvius opposite the superior quadrigeminal body (figs. 9A and 9B). They pass ventrally through the tegmentum, and emerge along two lines—a mesial and a postero-lateral—which meet behind and pass forwards at an acute angle with one another. The mesial line commences close to the upper border of the pons and extends upwards and outwards along the inner border of the cerebral peduncle, while the postero-lateral line is on the surface of the peduncle.

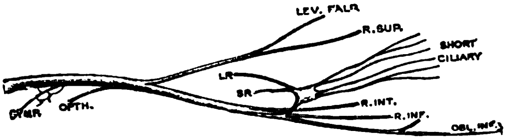

FIG. 6.—PLAN OF THE THIRD NERVE, WITH THE CILIARY GANGLION. (G. D. Thane.)

The ganglion is seen to be attached by its short root to the nerve of the inferior oblique muscle; LR, its long, and SR, its sympathetic root.

Speedily becoming firm and round, the nerve is directed from the interpeduncular space forwards, as well as somewhat outwards, through the subarachnoid space for a distance of about 20 mm., to the outer side of the posterior clinoid process, a little anterior to which it penetrates the layer of dura mater forming the outer boundary of the cavernous sinus. While in the subarachnoid space it passes between the posterior cerebral and superior cerebellar arteries.

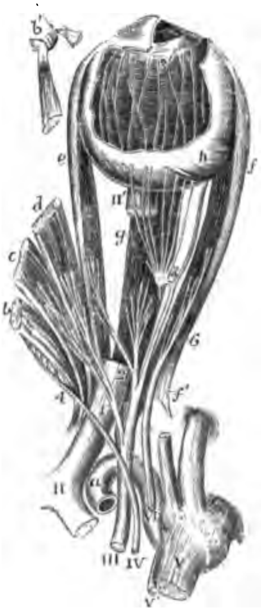

FIG. 7.—VIEW FROM ABOVE OF THE MOTOR NERVES OF THE EYEBALL AND ITS MUSCLES. (After Hirschfeld and Leveillé, altered.) (Allen Thomson.)

The ophthalmic division of the fifth pair has been cut short; the attachment of the muscles round the optic nerve has been opened up, and the three upper muscles turned towards the inner side, their anterior parts being removed; a part of the optic nerve is cut away to show the inferior rectus; and a part of the sclerotic coat and cornea is dissected off showing the iris, ciliary muscle, and choroid coat, with the ciliary nerves.

a, upper part of the internal carotid artery emerging from the cavernous sinus; *b*, superior oblique muscle; *b'*, its anterior part passing through the pulley; *c*, levator palpebræ superioris; *d*, superior rectus; *e*, internal rectus; *f*, external rectus; *f'*, its upper tendon turned down; *g*, inferior rectus; *h*, insertion of inferior oblique muscle.

II, optic commissure; II', part of the optic nerve entering the eyeball; III, common oculomotor; IV, trochlear nerve; V, large root of fifth; V', small or motor root; VI, abducent nerve; 1, upper division of third nerve, giving twigs to the levator palpebræ and superior rectus; 2, branches of lower division supplying the internal and inferior recti muscles; 3, the long branch of the same nerve proceeding forwards to the inferior oblique muscle, and close to the number 3, the short root of the ciliary ganglion: this ganglion is also shown, receiving from behind its long root, which has been cut short, and giving forward some of its ciliary nerves, which pierce the sclerotic coat; 3', marks the termination of some of these nerves in the ciliary muscle and iris after having passed between the sclerotic and choroid coats; 4, the trochlear nerve entering the upper surface of the superior oblique muscle; 6, the abducent nerve passing into the external rectus.

After piercing the dura mater, it continues its course forwards in the outer wall of the cavernous sinus to the inner end of the sphenoidal fissure, and divides about 37 mm. from its superficial origin into two parts, upper and lower, which enter the orbit between the heads of the external rectus muscle, and are separated from each other by the nasociliary branch of the ophthalmic nerve. As the third nerve lies in the outer wall of the cavernous sinus, it is said to be connected by slender filaments with the cavernous plexus of the sympathetic, and to receive also a small branch from the ophthalmic division of the fifth nerve, but Wakelin Barrett failed to find these communicating fibres.[1]

The *upper*, the smaller part, is directed inwards over the optic nerve to the superior rectus muscle of the eye and the elevator of the eyelid, to both of which muscles it furnishes branches.

The *lower* and larger portion of the nerve divides into three branches: of these one reaches the inner rectus; another the lower rectus; and the third, the longest of the three, runs onwards between the lower and the outer rectus, and terminates below the ball of the eye in the inferior oblique muscle. The last-mentioned branch is connected with the lower part of the ciliary ganglion by a short thick offset (*short root of the ganglion*), and gives one or two filaments to the lower rectus muscle.

The several branches of the third nerve enter the muscles to which they are distributed on the surface which in each is turned towards the eyeball, with the exception of that to the inferior oblique, which penetrates the hinder border of its muscle.

The medullated fibres of the third nerve, about 15,000 in number, are generally large (11 to 15 μ); but there are some small ones (3 to 5 μ), most of which pass into the ciliary ganglion. The nerve also contains a few non-medullated fibres, situated chiefly in its sheath. In the rootlets of the nerve Thomsen and Gaskell have described a peculiar structure which is regarded by them as the remains of a degenerated ganglion.[2]

Varieties.—A communication between the third and sixth nerves as they pass the cavernous sinus has been described, but its existence is denied by most recent observers. The upper division of the third nerve may have a communication with the nasociliary (Svitzer, Sœmmering, Testut). The third nerve has been seen in a few cases giving a branch to the external rectus (Cruveilhier, Fäsebeck, C. Krause), and in one instance a branch of the third supplied the place of the sixth nerve which was wanting (Generali). A filament to the superior oblique muscle is noticed by Volkmann. The branch to the inferior oblique muscle was seen by Arnold to pass through the lower part of the ciliary ganglion, and by Henle to pierce the inferior rectus.

Position of certain nerves at the cavernous sinus, and as they enter the orbit.—There are several nerves, besides the third, placed close together at the cavernous sinus, and entering the orbit through the sphenoidal fissure. To avoid repetition hereafter, the relative positions of these nerves may now be described. The nerves thus associated are the third, the fourth, the ophthalmic division of the fifth, and the sixth.

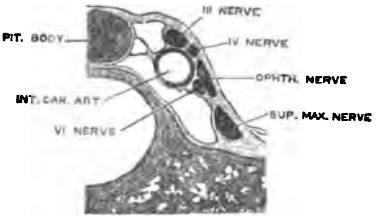

FIG. 8.—THE NERVES IN THE OUTER WALL OF THE CAVERNOUS SINUS, SEEN IN TRANSVERSE SECTION. (Langer.)

At the cavernous sinus.—In the dura mater which bounds the cavernous sinus on the outer side, the third and fourth nerves and the ophthalmic division of the fifth are placed, as regards one another, in their numerical order both from above downwards and from within outwards. The sixth nerve is placed separately from the others close to the carotid artery in the cavity of the sinus, and internally to the ophthalmic nerve. Near the sphenoidal fissure, through which they enter the orbit, the relative position of the nerves is changed, the sixth nerve being here close to the rest, and their number is augmented by the division of the third and the ophthalmic nerves—the former into two, the latter into three parts.

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[1] Journ. Anat. and Phys. xxxv.

[2] Virchow's Archiv, cix. 1887; Journ. Phys. x. 1889, p. 167.

In the sphenoidal fissure.—The fourth and the frontal and lacrymal branches of the ophthalmic division of the fifth, which are here higher than the rest, lie on the same level, the fourth being the nearest to the inner side, and enter the orbit above the muscles. The remaining nerves pass between the heads of the external rectus muscle, in the following order from above downwards: the upper division of the third, the naso-ciliary branch of the fifth, the lower division of the third, and, lowest of all, the sixth.

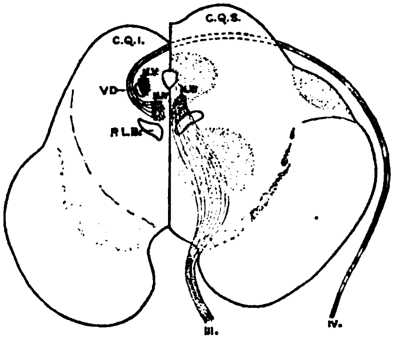


FIG. 9A.—PLAN OF THE ORIGINS OF THE THIRD AND FOURTH NERVES. (G. D. Thane.)

The mid-brain is supposed to be divided at different levels on the two sides, the section on the right side of the figure passing through the superior, and on the left side through the inferior quadrigeminal body: III., third nerve; N.III, its nucleus; IV., fourth nerve; N.IV, its nucleus; V.D, descending motor or mesencephalic root of the fifth nerve; N.V., its nucleus; C.Q.S., superior, and C.Q.I., inferior quadrigeminal body; P.L.B., dorsal (posterior) longitudinal bundle.

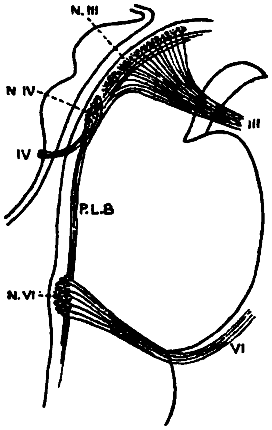


FIG. 9B.—PLAN OF THE ORIGINS OF THE THIRD, FOURTH, AND SIXTH NERVES. (Modified from Gowers.)

The nerves and their nuclei are projected into the outline of a median section of the mid-brain and pons: III, third nerve; N.III, its nucleus; IV, fourth nerve; N.IV, its nucleus; P.L.B., dorsal longitudinal bundle; VI, sixth nerve; N.VI, its nucleus.

FOURTH OR TROCHLEAR NERVE.

The **fourth** or **trochlear nerve** is the smallest of the cerebral nerves, and has the longest course (about 40 mm.) within the cranial cavity. It is distributed solely to the superior oblique muscle of the eye.

The nucleus of the fourth nerve continues downwards the column of cells giving origin to the third nerve, being placed in the ventral grey matter of the aqueduct of Sylvius opposite the upper part of the inferior quadrigeminal body (fig. 9). From the nucleus the fibres are directed at first downwards for a short distance, and then backwards and inwards, arching round the lower part of the aqueduct, to enter the superior medullary velum, where they cross to the opposite side, the two nerves thus forming a complete decussation.

Emerging from the upper end of the superior medullary velum close to the frenulum, and immediately below the inferior quadrigeminal body, the fourth nerve is directed at first outwards across the superior peduncle of the cerebellum, and then turns forwards round the outer side of the pedunculus cerebri (fig. 5), lying parallel to and between the posterior cerebral and superior cerebellar arteries. It enters an aperture in the dura mater immediately beneath the free margin of the tentorium, a little behind the posterior clinoid process, and runs forwards in the outer wall of the cavernous sinus, resting against the upper margin of the ophthalmic nerve, and crossing the third obliquely on its outer side from below upwards, to the inner end of the sphenoidal fissure. Passing into the orbit above the external rectus muscle, it inclines inwards over the levator palpebræ and superior rectus, and finally enters the superior oblique muscle on its upper surface, and close to its outer border.

While lodged in the outer wall of the sinus, the fourth nerve is connected with the sympathetic on the carotid artery, and is also joined by a filament from the ophthalmic nerve.

The fourth nerve consists of about 1,200 fibres, about three-fourths of large size (12 to 19 μ in diameter) and one-fourth small (4 μ). Like the third, it also shows close to its origin the vestiges of a degenerated ganglion (Gaskell).

Varieties.—In one case the fourth nerve pierced the levator palpebræ superioris on its way to the superior oblique (G. D. Thane). The nerve has been observed in several cases sending a branch forwards to the orbicularis palpebrarum muscle, or to join the supratrochlear, the infratrochlear, or the nasal nerve. A communication with the frontal nerve is recorded by Berté, and A. F. Dixon found it in a human embryo.

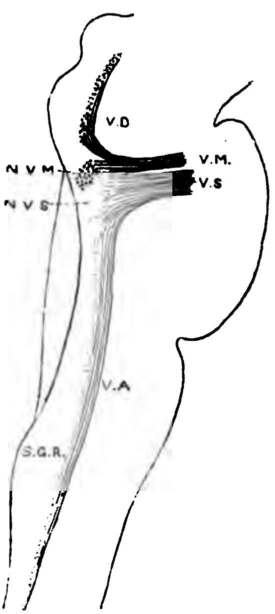


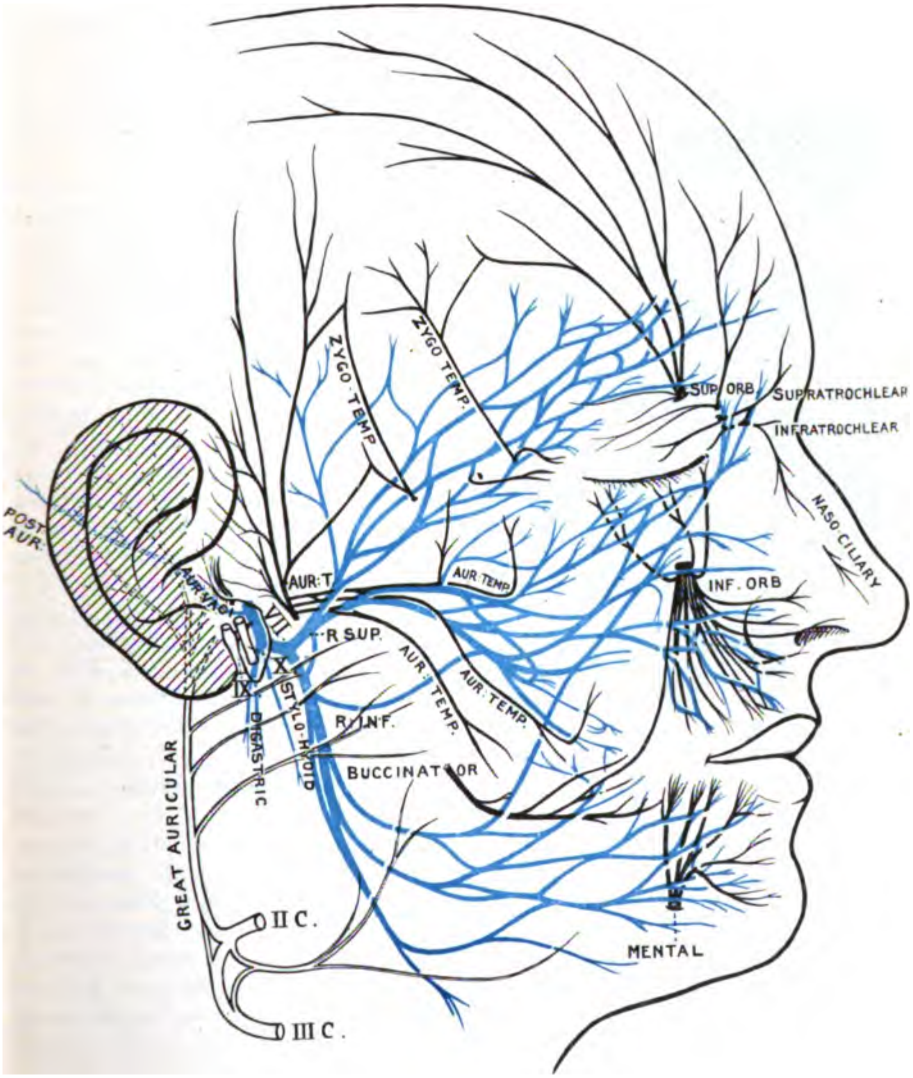
FIG. 10.—PLAN OF THE ORIGIN OF THE FIFTH NERVE. (G. D. Thane.)

The outline represents the contour of the medulla oblongata, pons, and a part of the mid-brain, which are supposed to be transparent: V.M., motor portion of the fifth nerve; N.V.M., the motor nucleus; V.D, descending motor or mesencephalic root; V.S., sensory portion of the fifth nerve; N.V.S, the upper sensory nucleus; V.A, sensory or bulbo-spinal root; S.G.R., gelatinous substance of Rolando, or lower sensory nucleus.

FIFTH OR TRIGEMINAL NERVE.

The **fifth** or **trigeminal nerve** is the largest of the cerebral nerves, and resembles a spinal nerve in the circumstance that it arises by separate sensory (portio major) and motor (portio minor) roots, and also that the sensory root has a ganglion upon it. It differs, however, in that three separate bundles issue from the peripheral side of the ganglion, and only one of these is joined by the motor root. Its sensory division, which is much the larger, imparts common sensibility to the face and the fore-part of the head, as well as to the eye, the nose, part of the external ear, the mouth, including the greater portion of the tongue, and the dura mater. The motor root supplies chiefly the muscles of mastication.

The fibres of the small root arise in part from the motor nucleus of the fifth nerve beneath the floor of the upper portion of the fourth ventricle; they are joined by the bundle known as the descending motor root of the fifth nerve, which springs from a long slender column of large nerve-cells extending in the grey matter from the motor nucleus upwards along the side of the cerebral aqueduct. The motor root issues from the pons above the sensory; the two are separated by a small band of the superficial transverse fibres of the pons. It then passes forwards and outwards under the sensory root and its ganglion, and after leaving the cranial cavity by the foramen ovale joins the sensory portion of the mandibular nerve. The sensory root is formed by the central processes of the cells of the semilunar ganglion. They pass backwards from the ganglion above the apex of the petrous portion of the temporal bone, lying with the motor root in a common tube of dura mater often termed the cavum Meckelii. Emerging from this tube and piercing the arachnoid, the fibres cross the subarachnoid space below the tentorium to reach the side of the pons at its union with the middle cerebellar peduncle. In the pons the fibres pass backwards, and some reach the upper sensory nucleus of the fifth nerve, placed to the outer side of and somewhat deeper than the motor nucleus; but the greater number turn downwards and are continued through the substance of the pons into the medulla oblongata and upper part of the spinal cord, forming the descending sensory or bulbar root of the fifth: they break up among the cells of the gelatinous substance of Rolando (terminal sensory nucleus of the fifth nerve).


ZYGO TEMP
ZYGO TEMP.
SUP. ORB.
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INFRATROCHLEAR
NASO CILIARY
POST AUR
AUR VAGI
AUR: T
AUR TEMP
INF. ORB
VII
R SUP.
X
IX
STYLO-HYOID
AUR. TEMP.
AUR. TEMP.
DIGASTRIC
R. INF.
BUCCINATOR
GREAT AURICULAR
II C.
MENTAL
III C.

Fig. 11.—Dissection of the face and pinna, showing the distribution of the fifth and seventh cerebral nerves and some spinal nerves. (Modified from Frohse.)

The small root consists mainly of large fibres, and contains a vestigial ganglion (Gaskell). The large root is mostly composed of fine fibres.

The **ganglion of the fifth nerve** or **ganglion semilunare** (*Gasserian ganglion*) occupies a depression on the upper surface of the petrous portion of the temporal bone, near the apex, and is somewhat crescentic in form, the convexity being turned forwards. It is flattened, and striated on the surface. Its internal part comes into close relation with the posterior extremity of the cavernous sinus and the internal carotid artery. On its inner side the ganglion is joined by filaments from the carotid plexus of the sympathetic nerve; and it furnishes from its back part filaments to the dura mater. The cells of this ganglion are similar to those found on the dorsal roots of the spinal nerves.

From the convex border of the semilunar ganglion proceed the three large divisions of the nerve. The highest (*first* or *ophthalmic trunk*) enters the orbit; the second, the *maxillary nerve*, is continued forwards to the face between the orbit and mouth; and the third, the *mandibular nerve*, is distributed chiefly to the external ear, the tongue, the lower teeth, the face below the mouth, and the muscles of mastication. The first two trunks proceed exclusively from the ganglion and are entirely sensory, while the third or mandibular trunk, derived principally from the ganglion, has associated with it also the whole of the fibres of the motor root, and thus distributes both motor and sensory branches.

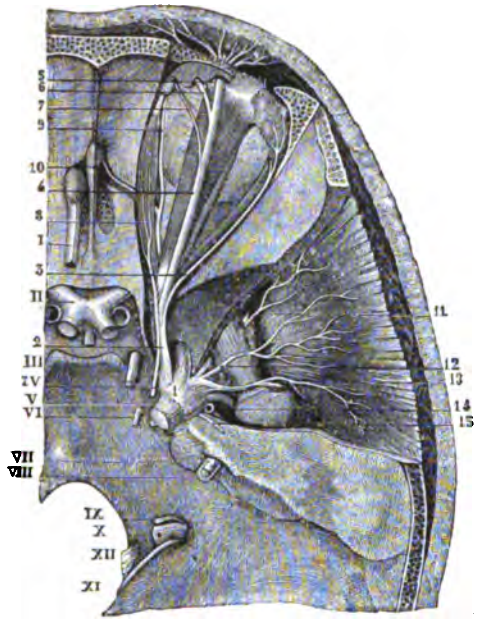

FIG. 12.—VIEW FROM ABOVE OF THE UPPERMOST NERVES OF THE ORBIT, THE SEMILUNAR GANGLION, ETC. (From Sappey, after Hirschfeld and Leveillé.) ⅔.

I, olfactory tract, passing forwards into the bulb; II, optic commissure; III, oculomotor; IV, trochlear nerve; V, large root of the fifth nerve: a small portion of the lesser root is seen below it; VI, sixth nerve; VII, facial; VIII, acoustic; IX, glossopharyngeal; X, vagus; XI, accessory; XII, hypoglossal; 1, semilunar ganglion; 2, ophthalmic nerve; 3, lacrymal nerve; 4, frontal; 5, external, 6, internal branch of the supra-orbital nerve; 7, supratrochlear nerve; 8, nasociliary nerve; 9, its infratrochlear branch; 10, nasociliary nerve, passing through the anterior internal orbital canal; 11, anterior deep temporal proceeding from the buccal nerve; 12, middle deep temporal; 13, posterior deep temporal arising from the masseteric; 14, origin of the auriculo-temporal; 15, great superficial petrosal nerve.

Ophthalmic nerve. — The ophthalmic nerve, or first division of the fifth, the smallest of the three offsets from the semilunar ganglion, is flattened from side to side, and measures about an inch in length. It is directed forwards and upwards in the outer wall of the cavernous sinus, in company with the third and fourth nerves, towards the sphenoidal fissure, where it ends in branches which pass through the orbit to the surface of the head and to the nasal fossa. In its course forwards, the ophthalmic nerve is joined by filaments from the cavernous plexus of the sympathetic.

A small *recurrent branch* (*nervus tentorii*) arises from the ophthalmic trunk near the semilunar ganglion, and, running backwards across the fourth nerve, to which it generally adheres closely for some distance, ramifies between the layers of the tentorium.

Farther forwards the ophthalmic nerve gives off three slender offsets which join respectively the third, fourth, and sixth nerves as they enter the orbit.

The terminal branches resulting from the division of the ophthalmic nerve close to the orbit are the naso-ciliary, which is usually the first to arise and springs from the inner and lower part of the trunk, the frontal, and the lacrymal. These branches are transmitted separately through the sphenoidal fissure, and are continued through the orbit (after supplying some filaments to the eyeball and the lacrymal gland) to their final distribution in the nose, the eyelids, and the integument of the forehead.

Lacrymal nerve.—The lacrymal nerve (fig. 12, 3) is external to the frontal at its origin, and is contained in a separate sheath of dura mater. In the orbit it passes along the outer part, above the external rectus muscle, to the outer and upper angle of the cavity. Near the lacrymal gland, the nerve has a connecting filament with the temporal branch of the maxillary nerve; and when in close apposition with the gland, it gives many filaments to that body and to the conjunctiva.

Varieties.—The lacrymal nerve is occasionally smaller than usual, being reinforced by a twig from the temporal branch of the maxillary, and it has been seen replaced entirely by an offset of the latter nerve (Turner, Hyrtl). On the other hand, the lacrymal nerve has been found sending an offset through the malar bone in the place of the temporal branch of the maxillary nerve, which was absent (Thane).

The lacrymal branch sometimes appears to be derived in part from the fourth nerve, but in such cases the additional root is probably composed of fibres that have passed over from the ophthalmic to the fourth, while these nerves are contained in the outer wall of the cavernous sinus. As a rule it does not supply any branches to the skin (Frohse).

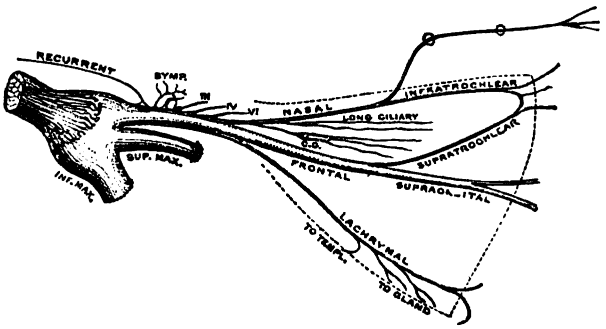

FIG. 18.—PLAN OF THE OPHTHALMIC NERVE. (G. D. Thane.)

The dotted line represents the limit of the orbit. C.G., ciliary ganglion, joined behind by the long root, and giving off in front the short ciliary nerves.

Frontal nerve.—The frontal nerve (fig. 12, 4), the largest division of the ophthalmic, also enters the orbit above the muscles, and runs forwards between the elevator of the upper eyelid and the periosteum. About the middle of the orbit it divides into two branches, supratrochlear and supra-orbital.

The *supratrochlear nerve*, much the smaller of the two branches, inclines inwards towards the pulley of the superior oblique muscle, close to which it sends a filament downwards to communicate in a loop with the infratrochlear branch of the naso-ciliary nerve, and then leaves the orbit between the orbicularis palpebrarum muscle and the bone. In this position the nerve gives twigs to the skin and conjunctiva of the upper eyelid, and finally it turns upwards, dividing into branches which perforate the orbicularis and frontalis muscles, and are distributed to the integument of the lower and mesial part of the forehead.

The *supra-orbital nerve* is the continuation of the frontal nerve, and leaves the orbit by the supra-orbital notch or oramen. It divides into two branches, inner and outer, which ascend on the forehead beneath the frontalis muscle, and are distributed by numerous slender ramifications to the skin of the fore and upper parts of the scalp. The outer branch is the larger, and extends backwards nearly to the lambdoid suture; the inner branch reaches but a little way over the parietal bone. In the supra-orbital notch a slender filament of the nerve enters an aperture in the frontal bone, where it is said to be distributed to the diploë and the mucous lining of the frontal sinus; as the nerve emerges from the orbit, twigs are sent downwards to the upper eyelid; and from its terminal divisions small branches pass to the pericranium.

The primary division of the supra-orbital nerve often takes place before it issues from the orbit, and in that case only the larger branch passes through the supra-orbital notch, the smaller one being placed more internally, and not unfrequently traversing a second slighter notch (*frontal notch*, Henle) in the orbital margin (fig. 12, 5, 6).

The branches of the supra-orbital nerve—and the same is the case with all the cutaneous offsets of the fifth—form communications with the adjacent ramifications of the facial nerve; in this way sensory fibres derived from the fifth nerve may be conveyed to the surrounding muscles.

Naso-ciliary or *nasal nerve.*—This nerve enters the orbit between the heads of the external rectus muscle, and between the two divisions of the third nerve. It then inclines inwards over the optic nerve, passing beneath the superior rectus and superior oblique muscles, to the inner side of the orbit, and leaves that cavity by the anterior internal orbital canal. In this part of its course it furnishes a slender branch to the ciliary ganglion, one or two filaments (long ciliary) directly to the eyeball, and a considerable infratrochlear branch, which arises just before the nerve enters its canal on the inner side of the orbit.

Arrived in the cranial cavity, the nerve is directed forwards in a groove at the outer edge of the cribriform plate of the ethmoid bone to a small canal between the fore-part of the plate and the frontal bone, through which it descends to the nasal fossa. Here it gives off internal or septal and external branches to the mucous membrane of the fore-part of the nasal fossa, and is then continued downwards in the groove on the back of the nasal bone, to terminate as the anterior or superficial branch in the integument of the lower part of the dorsum of the nose.

The *branch to the ciliary ganglion*, very slender, and from a quarter to half an inch in length, arises generally between the heads of the external rectus. It lies on the outer side of the optic nerve, and enters the upper and back part of the ganglion, constituting its *long root*.

The *long ciliary nerves* are situated on the inner side of the optic nerve; they join one or more of the short ciliary branches from the ciliary ganglion, and, after perforating the sclerotic coat of the eye, are distributed in the same manner as those nerves.

The *infratrochlear nerve* runs forwards along the inner side of the orbit, below the superior oblique muscle, and parallel to the supratrochlear nerve, from which it receives, near the pulley of the oblique muscle, a filament of connexion. The nerve is then continued below the pulley to the inner angle of the eye, and ends in filaments which supply the conjunctiva, the caruncle, and the lacrymal sac, as well as the integument of the upper eyelid and root of the nose.

The *internal* or *septal branch* (fig. 3, 3) supplies the pituitary membrane over the fore-part of the septum, extending downwards nearly as far as the opening of the nostril.

The *external branch* (fig. 19, 2), often represented by two or three filaments, is distributed to the mucous membrane of the fore-part of the outer wall of the nasal fossa, including the anterior ends of the middle and lower turbinate bones.

The *anterior* or *superficial branch* (fig. 11) issues between the nasal bone and the upper lateral cartilage of the nose, and runs downwards under cover of the compressor naris muscle to the tip of the nose, supplying the skin of the lower part of the organ.

Varieties.—The naso-ciliary nerve occasionally (frequently, Krause) gives filaments to the superior and internal recti muscles. A branch to the levator palpebræ superioris has also been met with (Fäsebeck). In one case filaments of communication passed from a small ganglion connected with the naso-ciliary nerve to the third and sixth nerves (Svitzer). In two instances Testut observed absence of the infratrochlear branch, its place being supplied by the supratrochlear nerve. Offsets from the naso-ciliary nerve, as it traverses the anterior internal orbital canal, to the frontal sinus and ethmoidal cells are described by Meckel and Langenbeck; and a *spheno-ethmoidal* (Luschka) or *posterior ethmoidal* (Krause) branch is said to pass through the posterior internal orbital canal to the mucous membrane of the sphenoidal sinus and posterior ethmoidal cells.

SUMMARY.—The ophthalmic or first division of the fifth nerve is altogether sensory in function. It furnishes branches to the dura mater; to the eyeball and the lacrymal gland; to the mucous membrane of the nose and eyelids; to the integument of the nose, the upper eyelid, the forehead, and the upper part of the hairy scalp. It has communications with the third, fourth, and sixth nerves, with numerous branches of the facial, and with the sympathetic.

There are four small ganglia usually described in connexion with the divisions of the fifth nerve: the ciliary ganglion with the first, the sphenopalatine ganglion with the second, and the otic and submaxillary ganglia with the third. These ganglia belong to the sympathetic system, but receive fibres from the sensory part of the fifth, and may in addition get motor, sensory, and secretory fibres from other cerebral nerves. The nerves thus joining the ganglia are termed their roots. Each ganglion gives off a number of branches of distribution.

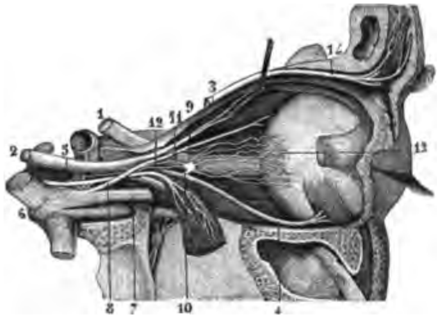

FIG. 14.—NERVES OF THE ORBIT FROM THE OUTER SIDE. (From Sappey, after Hirschfeld and Leveillé.) ¾.

The external rectus muscle has been divided and turned down: 1, optic nerve; 2, trunk of the third nerve; 3, its upper division passing into the levator palpebræ and superior rectus; 4, its long lower branch to the inferior oblique muscle; 5, the sixth nerve joined by twigs from the sympathetic; 6, semilunar ganglion; 7, ophthalmic nerve; 8, its naso-ciliary branch; 9, ciliary ganglion; 10, its short, 11, its long, and 12, its sympathetic root; 13, short ciliary nerves; 14, supra-orbital nerve.

Ciliary ganglion.—The ciliary ganglion serves as a centre for the supply of nerves—motor, sensory, and sympathetic—to the eyeball. It is a small reddish body, compressed laterally and somewhat four-sided, and measures about 2 mm. from before backwards. It is situated at the back of the orbit, between the outer rectus muscle and the optic nerve, and generally in contact with the ophthalmic artery; it is joined behind by branches from the fifth, the third, and the sympathetic nerves; while from its fore-part proceed the short ciliary nerves to the eyeball. The cells of the ganglion are of the multipolar variety.

Union of the ganglion with nerves: its roots.—The posterior border of the ganglion receives three nerves. One of these, the *long* or *sensory root*, a slender filament from the naso-ciliary branch of the ophthalmic trunk, joins the upper part of this border. Another branch, the *short* or *motor root*, much thicker and shorter than the preceding, and sometimes divided into two parts, is derived from the branch of the third nerve to the inferior oblique muscle, and is connected with the lower part of the ganglion. The *middle* or *sympathetic* *root* is a very small nerve which emanates from the cavernous plexus of the sympathetic, and reaches the ganglion close to the long upper root: these two nerves are frequently conjoined before reaching the ganglion. The ganglion is sometimes very small, probably from the nerve-cells being distributed along the nerves which are connected with it.

Branches of the ganglion.—From the fore-part of the ganglion arise six or eight *short ciliary nerves,* which undergo division as they pass forwards, so that they form from twelve to twenty fine filaments as they reach the eyeball. They are disposed in two bundles, springing from the upper and lower angles of the ganglion, and being placed, the one set above, the other below the optic nerve. The lower set is the more numerous, and is accompanied by the long ciliary nerves (from the naso-ciliary), with which one or more of these branches are joined. Having entered the eyeball by apertures in the back part of the sclera, the nerves are lodged in grooves on the inner surface of this coat, and are finally distributed to the ciliary muscle, the iris, and the cornea (see the anatomy of the eye).

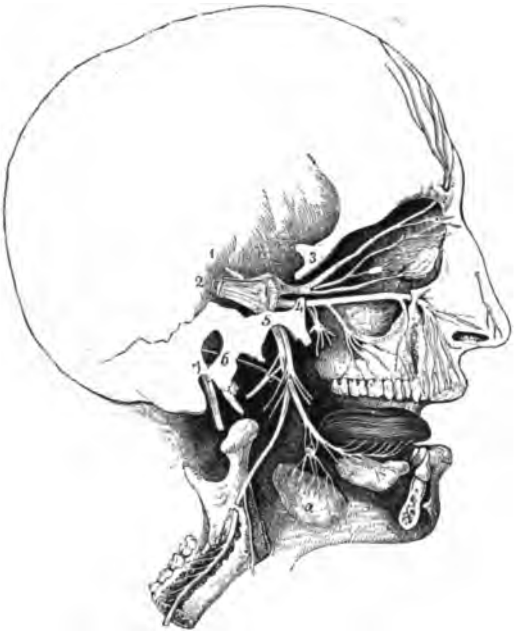

FIG. 15. — GENERAL PLAN OF THE BRANCHES OF THE FIFTH PAIR. (After a sketch by Charles Bell.) ⅓.

1, small root of the fifth nerve; 2, large root, passing forwards into the semilunar ganglion; 3, placed on the bone above the ophthalmic nerve, which is dividing into the frontal, lacrymal, and naso-ciliary branches, the latter connected with the ciliary ganglion; 4, placed on the bone close to the foramen rotundum, marks the maxillary division, which is connected below with the spheno-palatine ganglion, and passes forwards to the infra-orbital foramen; 5, placed on the bone over the foramen ovale, marks the mandibular nerve, giving off the auriculo-temporal and muscular branches, and continued by the inferior dental to the lower jaw, and by the lingual to the tongue; *a*, submaxillary gland, the submaxillary ganglion placed above it in connexion with the lingual nerve; 6, chorda tympani; 7, facial nerve, issuing from the stylomastoid foramen.

Varieties.—Additional roots to the ciliary ganglion have been observed by many anatomists, derived from the upper division of the third nerve, from the fourth nerve, from the lacrymal nerve, from the sphenopalatine ganglion, or from the sixth nerve.

Absence of the long root is recorded: in this case it is probable that the corresponding fibres pass directly from the naso-ciliary by the long ciliary nerves to the eyeball.

The sympathetic root may be represented by several fine filaments proceeding from the cavernous plexus: according to Reichart this is the normal arrangement, the majority of the filaments accompanying the third nerve.

Maxillary nerve (*superior maxillary*).—The maxillary nerve, or second division of the fifth, is intermediate in size between the ophthalmic and the mandibular trunks.

It commences at the middle of the semilunar ganglion, and, passing horizontally forwards, soon leaves the skull by the foramen rotundum of the sphenoid bone. The nerve then crosses the sphenomaxillary fossa, and, taking the name of *infra-orbital,* enters the infra-orbital canal of the maxilla, by which it is conducted to the face. After emerging from the infra-orbital foramen, it terminates beneath the elevator of the upper lip in branches, which spread out to the side of the nose, the lower eyelid, and the upper lip.

Near its origin a fine *recurrent branch* (*n. meningeus medius*) passes to the dura mater and middle meningeal artery. In the sphenomaxillary fossa a zygomatic branch ascends from the maxillary nerve to the orbit, and two sphenopalatine branches descend to the sphenopalatine ganglion. While the nerve is in contact with the maxilla, it furnishes the superior dental or alveolar branches; and on the face are the terminal branches already indicated.

Zygomatic branch.—The *nervus zygomaticus* (temporo-malar) is a small cutaneous nerve; it enters the orbit by the sphenomaxillary fissure, and immediately divides into two branches (temporal and facial), which pierce the malar bone, and are distributed to the temple and the prominent part of the cheek.

The *ramus zygomatico-temporalis* (*temporal branch*) is directed upwards in a groove on the outer wall of the orbit, and leaves this cavity by the temporal canal in the malar bone. While still in the orbit, it is joined by a communicating filament (in some cases by two filaments) from the lacrymal nerve. The nerve is then inclined upwards in the temporal fossa between the bone and the temporal muscle, and perforating the aponeurosis over the muscle nearly an inch above the zygoma, ends in cutaneous filaments over the fore-part of the temporal region. The cutaneous ramifications are united with the facial nerve, and sometimes with the auriculo-temporal branch of the third division of the fifth.

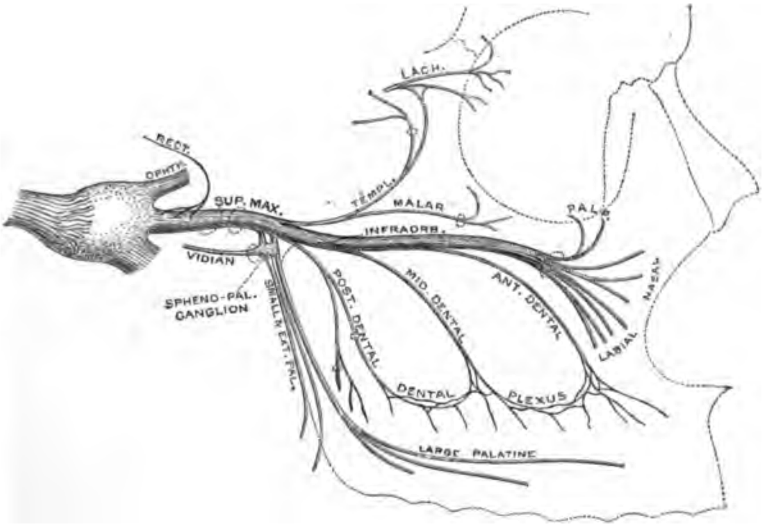

FIG. 16.—PLAN OF THE MAXILLARY NERVE. (G. D. Thane.)

The *ramus zygomatico-facialis* (*facial branch*) lies at first in the loose fat in the lower angle of the orbit, and is continued to the face through the malar canal of the malar bone, where it is frequently divided into two filaments. It is distributed to the skin over the malar bone, after forming a communication with the facial nerve.

Varieties.—The zygomatic nerve is subject to frequent deviations from the arrangement above described. Thus, either branch may be smaller than usual, or even absent, in which case the other division of the nerve may be distributed over a larger area, or the temporal branch may be reinforced or replaced by the lacrymal nerve, the facial branch by the infra-orbital nerve. The temporal branch, instead of perforating the malar bone, frequently passes into the temporal fossa through the anterior end of the sphenomaxillary fissure. The facial branch is always small, while the temporal varies considerably in size.

The *superior dental* or *alveolar nerves* are, as a rule, three in number—anterior, middle, and posterior, but the middle is sometimes conjoined with the anterior, while the posterior is frequently represented by two separate offsets.

The *posterior superior dental nerve* arises from the maxillary trunk before it enters the infra-orbital groove, and immediately divides into two branches (often separate at their origin), which descend with the posterior dental artery on the zygomatic surface of the upper jaw. They send small external filaments to the gum and the adjacent part of the mucous membrane of the cheek, and then enter the posterior dental canals to terminate in offsets to the molar teeth and the lining membrane of the antrum.

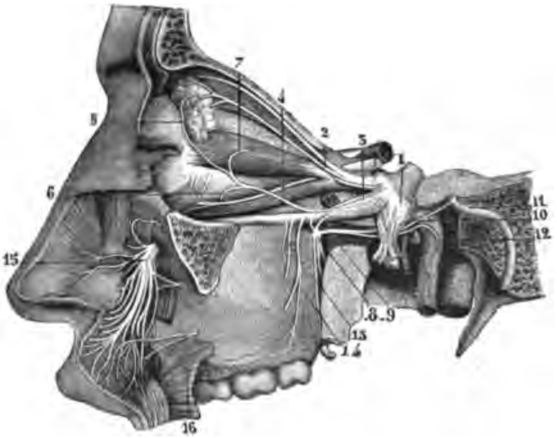

FIG. 17.—MAXILLARY NERVE AND SOME OF THE ORBITAL NERVES.
(From Sappey, after Hirschfeld and Leveillé.) $\frac{3}{5}$.

1, Semilunar ganglion; 2, lacrymal nerve; 3, trunk of the maxillary nerve; 4, its zygomatic branch; 6, origin of its facial twig; 7, its temporal twig, joined by 5, the communicating branch from the lacrymal nerve; 8, sphenopalatine ganglion; 9, Vidian nerve; 10, great superficial petrosal nerve proceeding to join 11, the facial nerve; 12, great deep petrosal nerve joining the sympathetic; 13, 14, posterior dental nerves; 15, terminal branches of the infra-orbital nerve in the face; 16, a branch of the facial uniting with some of the twigs of the infra-orbital.

Variety.—The posterior dental nerve has been seen in a few instances of large size, and replacing the buccal nerve, which was absent as a branch of the mandibular, in the supply of the cheek.

The *middle superior dental nerve* leaves the maxillary in the hinder part of the infra-orbital canal, and is directed downwards and forwards in a special canal in the outer wall of the antrum to the bicuspid teeth.

The *anterior superior dental nerve* is the largest of the three. Arising near the infra-orbital foramen, it descends in its canal in the front wall of the antrum, and divides into *dental branches* for the incisor and canine teeth, and a *nasal branch* which supplies the mucous membrane in the fore-part of the inferior meatus and the adjoining part of the floor of the nasal fossa.

The three dental nerves communicate so as to form loops with one another while they are contained in their bony canals, and from these loops other branches spring, which join again and give rise to a plexus (*superior dental plexus*) from which the minute terminal filaments proceed to the teeth and gum.

Facial branches.—The facial branches are divisible into palpebral, nasal, and labial sets.

The *inferior palpebral branches*, generally an inner and an outer, ascend from the termination of the infra-orbital nerve to supply the skin and conjunctiva of the lower eyelid in its whole breadth.

The *lateral nasal branches*, two or three in number, are directed inwards between the fibres of the levator labii superioris alæque nasi muscle to the skin of the side of the nose.

The *superior labial branches*, the largest of the terminal offsets of the maxillary nerve, and three or four in number, pass downwards between the elevator muscles of the upper lip and of the angle of the mouth. Ramifying as they descend, and giving off branches to supply the integument of the fore-part of the cheek, they end in the skin and mucous membrane of the upper lip.

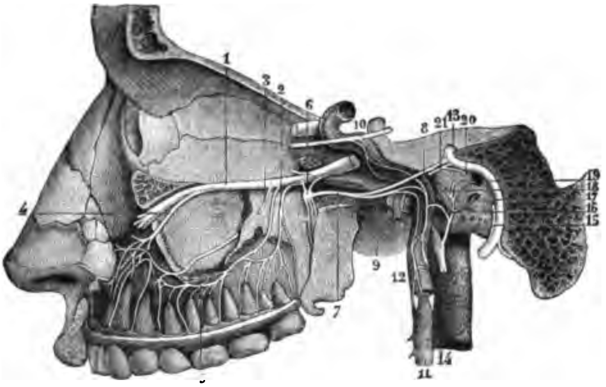

FIG. 18.—DEEP VIEW OF THE MAXILLARY NERVE AND THE SPHENOPALATINE GANGLION, ETC. (From Sappey, after Hirschfeld and Leveillé.) $\frac{3}{5}$.

1, maxillary nerve; 2, posterior superior dental; 3, middle superior dental; 4, anterior superior dental; 5, superior dental plexus; 6, sphenopalatine ganglion; 7, Vidian nerve; 8, great superficial petrosal; 9, great deep petrosal; 10, a part of the sixth nerve, receiving twigs from the carotid plexus of the sympathetic; 11, superior cervical sympathetic ganglion; 12, its ascending branch; 13, facial nerve; 14, glossopharyngeal nerve; 15, its tympanic branch; 16, carotico-tympanic twig joining the sympathetic; 17, filament to the fenestra cochleæ; 18, filament to the Eustachian tube; 19, filament to the fenestra vestibuli; 20, small superficial petrosal nerve.

Below the orbit, the terminal branches of the maxillary nerve are joined by considerable branches of the facial nerve, the union between the two being named the *infra-orbital plexus*.

Sphenopalatine ganglion.—The sphenopalatine ganglion, also named *Meckel's* or the *nasal ganglion*, is deeply placed in the sphenomaxillary fossa, close to the sphenopalatine foramen. It is of a reddish-grey colour, triangular in form, and convex on the outer surface, and measures from before back about 5 mm.

Roots of the ganglion.—Sensory fibres from the maxillary nerve as it crosses the sphenomaxillary fossa descend in two bundles and form the sphenopalatine roots of the ganglion. Another sensory root is derived from the geniculate ganglion on the facial nerve, and is known as the *large superficial petrosal nerve*. It passes from the geniculate ganglion through the hiatus Fallopii on to the anterior surface of the petrous portion of the temporal bone, then beneath the semilunar ganglion to the outer side of the internal carotid artery. Here it is joined by the sympathetic root (*great deep petrosal nerve*) of the sphenopalatine ganglion, and the united trunk, called the *Vidian nerve*, passes forwards through the Vidian canal to join the posterior part of the sphenopalatine ganglion. The *great deep petrosal nerve* is of a reddish colour, shorter and softer in texture than the large superficial petrosal. It arises from the sympathetic plexus on the internal carotid artery, and runs forwards on this artery to join the large superficial petrosal.

The grey matter of the sphenopalatine ganglion does not involve all the fibres of the sphenopalatine branches of the maxillary nerve, but is placed at the back part, at the point of junction of the Vidian nerve, so that many of the fibres of the sphenopalatine nerves proceeding to the nose and palate pass to their destination without being incorporated with the ganglionic mass. The ganglion may also receive fibres from the glossopharyngeal nerve, conveyed to it through the small and large deep petrosal nerves (p. 33, and fig. 29): this connexion is sometimes described as a third sensory root.

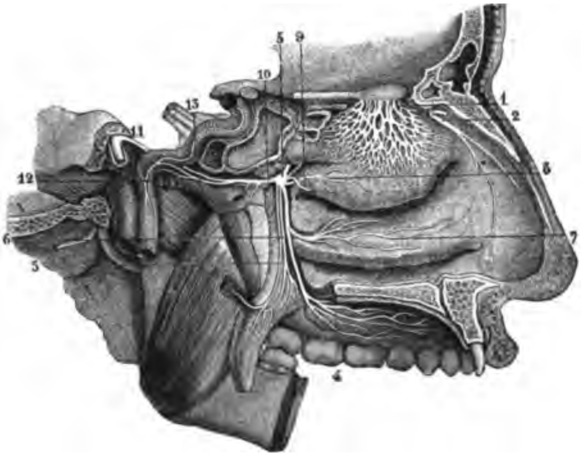

FIG. 19.—NERVES OF THE NOSE AND THE SPHENOPALATINE GANGLION FROM THE INNER SIDE. (From Sappey, after Hirschfeld and Leveillé.) $\frac{3}{5}$.

1, network of the external branches of the olfactory nerve: the area of distribution is not so large as represented here, and its fibres do not join to form a network; 2, naso-ciliary nerve, giving its external branch to the outer wall of the nose: the septal branch is cut short; 3, sphenopalatine ganglion; 4, ramification of the large palatine nerve; 5, small, and 6, external palatine nerve; 7, inferior nasal branch; 8, superior nasal branch; 9, naso-palatine nerve cut short; 10, Vidian nerve; 11, great superficial petrosal nerve; 12, great deep petrosal nerve; 13, the sympathetic nerves ascending on the internal carotid artery.

Branches proceed from the ganglion upwards to the orbit, downwards to the palate, inwards to the nose, and backwards through the pterygopalatine canal.

Ascending branches.—These are two or three very small twigs, which reach the orbit by the sphenomaxillary fissure, and are distributed to the periosteum and, according to Luschka, to the mucous membrane of the posterior ethmoid and sphenoid sinuses.

Bock and Valentin describe a branch ascending from the ganglion to the sixth nerve; Tiedemann, one to the lower angle of the ciliary ganglion. Hirzel and Arnold traced filaments to the optic nerve or its sheath.

Descending branches.—These are three in number—the large, the small, and the external palatine nerves, and are in great part continued directly from the sphenopalatine branches of the maxillary.

The *large* or *anterior palatine nerve* descends in the palatomaxillary canal, and divides in the roof of the mouth into branches which are received into grooves in the hard palate, and extend forwards nearly to the incisor teeth. In the mouth it supplies the inner side of the gum, the glands, and the mucous membrane of the hard palate, and joins in front with the nasopalatine nerve. While in its canal, the large palatine nerve gives off one or two *inferior nasal* branches, which supply the mucous membrane over the greater part of the inferior turbinate bone, together with the adjoining middle and inferior meatuses of the nose.

The *small* or *posterior palatine nerve* enters the lesser palatine canal, and is conducted to the soft palate, the tonsil, and the uvula.

The *external palatine nerve,* the smallest of the series, courses through the external palatine canal between the maxilla and the tuberosity of the palate bone, to be distributed to the tonsil and the outer part of the soft palate. This nerve is occasionally wanting.

Internal branches.—These consist of the nasopalatine, and the upper nasal branches, which ramify in the lining membrane of the nasal fossæ and adjoining sinuses.

The *upper nasal* are very small branches, and enter the back part of the nasal fossa by the sphenopalatine foramen. Some are prolonged to the upper and posterior part of the septum, and the remainder ramify in the membrane covering the upper two spongy bones, and in that lining the posterior ethmoidal cells.

The *nasopalatine nerve* (fig. 3, 3), long and slender, leaves the inner side of the ganglion with the preceding branches, and after crossing the roof of the nasal fossa is directed downwards and forwards, in a slight groove on the vomer, towards the anterior palatine canal. The nerves of opposite sides descend to the palate through the median subdivisions of the canal, called the foramina of Scarpa, the nerve of the right side usually behind that of the left. In the lower common foramen the two nasopalatine nerves are connected with each other in a fine plexus; and they end in several filaments, which are distributed to the mucous membrane behind the incisor teeth, and communicate with the great palatine nerve. In its course along the septum, small filaments are furnished from the nasopalatine nerve to the mucous membrane.

Posterior branch.—The *pharyngeal nerve* is small, and springs from the back of the ganglion, often in common with the Vidian nerve. It enters the pterygopalatine canal with an artery, and is lost in the lining membrane of the pharynx behind the Eustachian tube.

SUMMARY.—The maxillary nerve, with the sphenopalatine ganglion, supplies the integument of the cheek and the fore-part of the temple, the lower eyelid, the side of the nose, and the upper lip; the upper teeth; the lining membrane of the nose; the mucous membrane of the upper part of the pharynx, of the maxillary antrum, and of the posterior ethmoidal cells; the soft palate, tonsil, and uvula, and the glandular and mucous structures of the roof of the mouth.

Mandibular nerve (*inferior maxillary*).—This nerve, the third and largest division of the fifth, is made up of two portions of unequal size, the larger being derived from the semilunar ganglion, and the smaller being the slender motor root of the fifth nerve. These two parts leave the skull by the foramen ovale in the sphenoid bone, and unite immediately after their exit. Three or four millimetres below the base of the skull, and under cover of the external pterygoid muscle, the nerve separates into two primary divisions, one of which is higher in position and smaller than the other.

The *small, anterior,* or *upper portion* (*n. masticatorius*) receives the greater part of the fibres of the motor root, and breaks up into temporal, masseteric, external pterygoid, and buccal branches, of which the last alone is a sensory nerve. The *large, posterior*, or *lower portion* is chiefly sensory, and divides into auriculo-temporal, lingual, and inferior dental nerves; it likewise supplies through the last-mentioned branch the mylohyoid muscle and the anterior belly of the digastric. The branch to the internal pterygoid muscle, with which also are connected those proceeding through the otic ganglion to the tensors of the palate and tympanum, is sometimes counted as a part of the larger division, but is more correctly regarded as arising from the undivided trunk.

The short trunk of the nerve also gives off, as it issues from the foramen ovale, a slender *recurrent branch* (*n. spinosus*), which passes backwards into the skull through the foramen spinosum with the middle meningeal artery, and divides like that vessel into two branches. The anterior of these sends its filaments into the great wing of the sphenoid bone, while the posterior traverses the petro-squamous fissure, and is distributed to the mucous lining of the mastoid cells (Luschka).

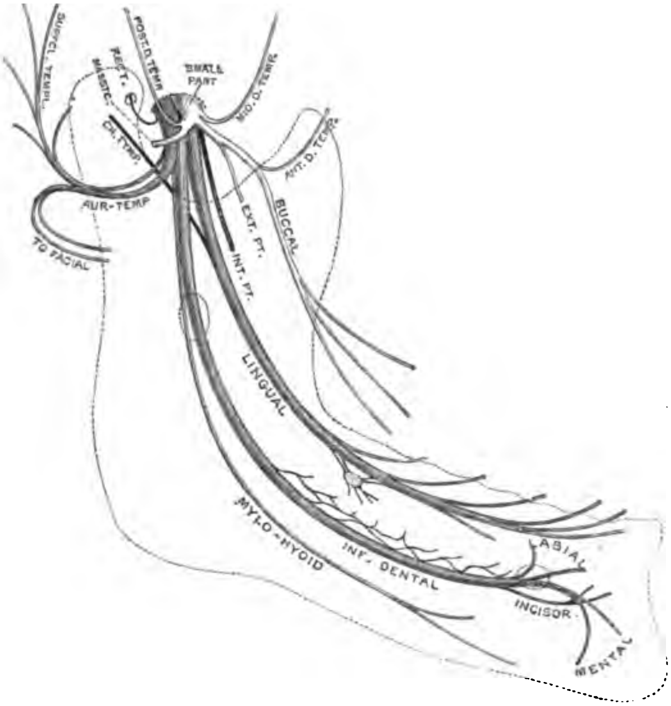

FIG. 20.—PLAN OF THE MANDIBULAR NERVE. (G. D. Thane.)

From the sheath which the mandibular nerve receives from the dura mater in its passage through the foramen ovale tubular prolongations are continued on the several offsets of the trunk. Those containing the masseteric and auriculo-temporal nerves are of considerable strength, and become blended with the capsule of the temporomaxillary articulation in front and on the inner side respectively, so that they are exposed to a certain degree of traction during the movements of the lower jaw.[1]

Varieties.—One or more of the branches of the superior division of the nerve may arise separately from the main trunk.

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[1] E. Fawcett, Journ. Anat. xxvii. 1893, p. 179.

There is not unfrequently a small fibrous band (*pterygo-sphenoid ligament*) extending from the root of the external pterygoid plate to a spot on the great wing of the sphenoid a little in front of the foramen spinosum, and lying in the angle between the two divisions of the mandibular nerve. In rare cases this band is replaced by bone, so that the small part of the nerve passes out through a special foramen on the under side of the great wing of the sphenoid, just external to the foramen ovale.[1]

The *deep temporal nerves* (figs. 12 and 21) are usually three in number, but are subject to considerable variety in their arrangement. The *anterior* is given off by the buccal nerve after it has perforated the external pterygoid, and ascends to supply the foremost part of the temporal muscle. The *middle* passes outwards above the external pterygoid and turns upwards close to the bone to enter the deep surface of the muscle. The *posterior* is generally conjoined with the masseteric nerve, and, taking a course similar to the middle branch, ramifies in the hinder part of the muscle. The number of these nerves is frequently reduced by the union of the middle with either of the other branches.

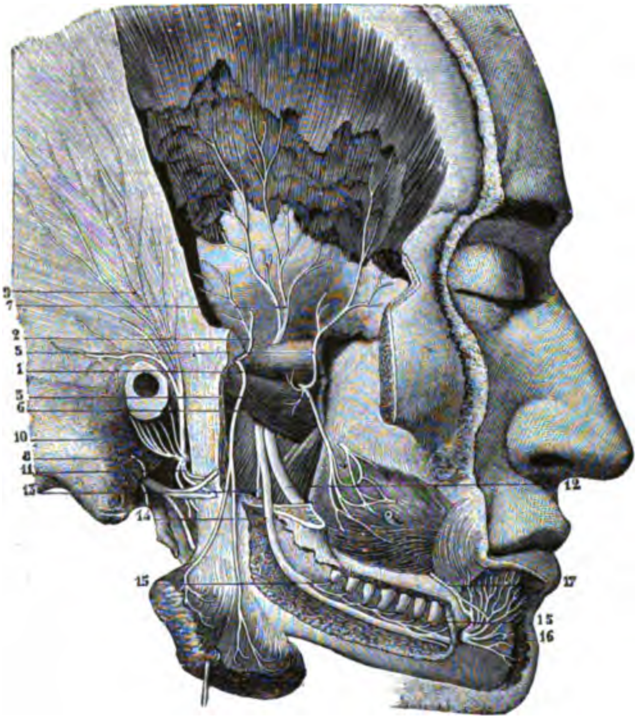

FIG. 21.—VIEW OF THE BRANCHES OF THE MANDIBULAR NERVE FROM THE OUTER SIDE. (From Sappey, after Hirschfeld and Leveillé.) ⅔.

The zygoma and part of the ramus of the lower jaw have been removed; the dental canal has been opened up; the lower part of the temporal muscle has been taken away, and the masseter muscle turned down: 1, masseteric nerve; 2, posterior deep temporal nerve; 3, buccal nerve; 4, branch of the facial; 5, anterior deep temporal nerve; 6, filaments given by the buccal to the external pterygoid muscle; 7, middle deep temporal nerve; 8, auriculo-temporal nerve; 9, its temporal branches; 10, its branches to the meatus and auricle; 11, its union with the facial; 12, lingual nerve; 13, mylohyoid nerve; 14, inferior dental nerve; 15, its twigs to the teeth; 16, mental branch; 17, branch of the facial uniting with the mental.

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[1] Hyrtl, Wiener Sitzungsber. 1862; A. v. Brunn, Anat. Anz. vi. 1891; U. Grosse, Anat. Anz. viii. 1893; J. Yule Mackay, in Report of Committee of Collective Investigation of Anat. Soc., Journ. Anat. xxviii. 1893, p. 67.

The *masseteric nerve* likewise passes above the external pterygoid, and is directed nearly horizontally outwards at the posterior border of the temporal muscle, and through the sigmoid notch of the lower jaw, to the masseter, which it enters at the hinder part of its deep surface. It also gives a filament or two to the articulation of the jaw.

The *external pterygoid nerve* generally arises in common with the buccal branch, and penetrates the inner surface of its muscle.

The *buccal nerve*, which differs from the foregoing branches in being entirely a sensory nerve, is usually conjoined at its origin with the anterior deep temporal and the external pterygoid nerves. It passes forwards between the heads of the external pterygoid, and then descends in close contact with the inner side (occasionally perforating some of the fibres) of the temporal muscle at its insertion, to the surface of the buccinator muscle. Here it divides into several branches which join in a plexus round the facial vein with the buccal branches of the facial nerve, and are finally distributed to the skin and mucous membrane of the cheek, extending as far forwards as the angle of the mouth.

Varieties.—The buccal nerve is occasionally replaced by a branch of the maxillary (p. 20). It has been seen by Turner arising from the inferior dental nerve in the dental canal, and issuing by a small foramen in the alveolar border of the lower jaw, close to the ramus. Gaillet describes it in one case as arising directly from the semilunar ganglion, and passing from the cranium through a special aperture between the round and oval foramina.

The *internal pterygoid nerve* (fig. 24, 13) is closely connected at its origin with the otic ganglion, and descends to the inner or deep surface of its muscle, being separated from the lingual and inferior dental nerves by the pterygo-spinous ligament when that band is present. From this nerve mainly, as it passes the otic ganglion, arise the small branches to the tensor palati and tensor tympani muscles.

Auriculo-temporal nerve.—The auriculo-temporal nerve takes its origin close to the foramen ovale, usually by two roots which embrace the middle meningeal artery. It is directed at first backwards, beneath the external pterygoid muscle, to the inner side of the neck of the lower jaw; then changing its course, it turns upwards between the ear and the temporo-maxillary articulation, under cover of the upper end of the parotid gland; and finally, emerging from beneath the latter, it ascends over the base of the zygoma in company with the superficial temporal artery, behind which it is placed, to terminate on the side of the head as the superficial temporal nerve.

Branches.—*Communicating branches.*—The roots of the auriculo-temporal nerve are joined, close to their origin, by slender filaments from the otic ganglion; and from the trunk of the nerve, as it turns upwards, one or two considerable branches are sent forwards round the commencement of the superficial temporal artery to the temporo-facial division of the facial nerve. These branches, which join the temporo-facial division in the parotid gland, can in some cases be easily separated from the motor fibres and traced to a considerable, though variable, area of skin between the fields supplied by the second division of the fifth and the great auricular. According to Frohse,[1] the most usual arrangement is for these fibres to pass by three branches to their distribution: an *upper* which courses along the lower edge of the zygomatic arch and sends twigs upwards over the arch, a *middle* to the angle of the mouth, and a *lower* towards the chin.

The *articular branches* are one or two fine twigs to the hinder part of the temporo-maxillary articulation.

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[1] Die oberflächlichen Nerven des Kopfes, 1895.

The *nerves of the external auditory meatus* are two in number, upper and lower, and enter the canal between the osseous and cartilaginous parts of its wall. They supply the skin of the anterior wall and roof of the meatus, and the upper one sends a filament to the membrana tympani.

The *anterior auricular nerves* are usually two in number, and supply the skin of the tragus, the crus, and ascending limb of the helix.

Parotid branches pass from the nerve, or from its connecting branches with the facial, to the gland.

The *superficial temporal nerve* divides into slender branches which supply the skin over the greater part of the temporal region, the anterior ones forming communications with the zygomatico-temporal.

Inferior dental nerve.—The inferior dental (*nervus alveolaris inferior*) is the largest of the branches of the mandibular nerve. It descends under cover of the external pterygoid muscle, behind and to the outer side of the lingual nerve, and, passing between the ramus of the jaw and the internal lateral ligament of the temporo-maxillary articulation, enters the inferior dental canal. In company with the dental artery, it proceeds along this canal, and supplies branches to the teeth. At the mental foramen it bifurcates; one part, the incisor branch, being continued onwards within the bone towards the middle line, while the other, the much larger mental branch, escapes by the foramen to the face.

When about to enter the foramen on the inner surface of the ramus of the jaw, the inferior dental nerve gives off the slender mylohyoid branch.

Branches.—The *mylohyoid branch* descends in the groove on the inner side of the ramus of the lower jaw to the under surface of the mylohyoid muscle, to which and to the anterior belly of the digastric it is distributed. The fibres of this nerve may be traced back within the sheath of the inferior dental to the motor root of the mandibular nerve.

The *dental branches* supply the molar and bicuspid teeth, together with the adjoining part of the gum. They form by their communications a fine *inferior dental plexus*, resembling that formed by the corresponding nerves in the upper jaw.

The *incisor branch* continues the direction of the trunk of the nerve, and supplies filaments to the canine and incisor teeth.

The *mental* or *labial nerve*, emerging from the bone by the mental foramen, divides beneath the depressor anguli oris into three parts—an inferior, which descends to the integument of the chin, and two superior, which ascend to the skin and mucous membrane of the lower lip. All three communicate freely with the mandibular branch of the facial nerve.

Varieties.—The inferior dental and lingual nerves have been observed to form a single trunk as far as the dental foramen. On the other hand, they are often separated by an accessory ligament stretched between the external pterygoid plate and the spine of the sphenoid, to the outer side of the pterygo-spinous ligament.[1] The inferior dental nerve is occasionally perforated by the internal maxillary artery. It sometimes has one or two accessory roots from other divisions of the mandibular. The most common of these is one which arises from the semilunar ganglion and remains separate until after it enters the dental canal (*lesser inferior dental nerve*, Sapolini).

The mylohyoid nerve frequently (constantly, Sappey) gives off a small branch, which pierces the mylohyoid muscle and joins the lingual nerve. Branches are also described as passing from the mylohyoid nerve to the depressor anguli oris and platysma myoides muscles (Henle), to the integument below the chin (Krause, Schwalbe, and others), and to the submaxillary gland (Meckel, Henle, Curnow).

Lingual nerve.—The lingual branch descends under cover of the external pterygoid muscle, lying to the inner side and in front of the inferior dental nerve, and generally united to that by a cord which may cross over the internal maxillary artery. Near its origin, it is joined at an acute angle by the *chorda tympani*, a small branch which is given off by the facial nerve, and which descends from the inner end of the Glaserian fissure. The lingual then passes between the internal pterygoid muscle and the ramus of the lower jaw, and is inclined obliquely inwards to the side of the tongue, over the upper constrictor of the pharynx (where this muscle is attached to the jaw), and above the deep portion of the submaxillary gland. Lastly, the nerve crosses below Wharton's duct, and is continued along the side of the tongue to the apex, lying immediately beneath the mucous membrane.

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[1] See v. Brunn, *op. cit.* p. 244.

Branches. — *Communicating branches.* — In addition to the cord above mentioned passing from the inferior dental to the lingual nerve, and the connexion with the facial nerve through the chorda tympani, the lingual nerve gives off branches to the submaxillary ganglion at the place where it is in contact with the submaxillary gland, and a little farther forwards one or two filaments descend over the fore-part of the hyoglossus muscle to join in loops with similar branches of the hypoglossal nerve.

Branches to the mucous membrane of the mouth are given from the nerve at the side of the tongue, and supply also the gum. Some delicate filaments are likewise distributed to the sublingual gland.

The *lingual* or *terminal branches* perforate the muscular structure of the tongue, and divide into filaments which are directed upwards to the mucous membrane of the anterior two-thirds of the organ, where they terminate mainly in the conical and fungiform papillæ. Microscopic ganglia are found in their ultimate ramifications.

Submaxillary ganglion.—The submaxillary ganglion (fig. 22; fig. 35, 7) is placed above the deep portion of the submaxillary gland, and is connected by anterior and posterior filaments with the lingual nerve, from which it thus appears to be suspended by a loop. It is somewhat larger than the ciliary ganglion, and triangular or fusiform in shape. Its hinder part receives branches from nerves which may be regarded as its roots, while from its fore and lower parts proceed the branches for distribution.

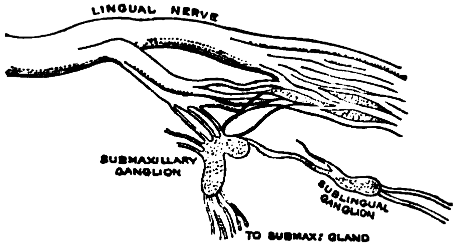


FIG. 22.—SUBMAXILLARY AND SUBLINGUAL GANGLIA OF AN INFANT. (Rauber.) $\frac{4}{1}$.

Roots of the ganglion.—The posterior connecting branch from the lingual nerve, often broken up into two or three filaments, conveys to the ganglion fibres from the chorda tympani and the mandibular nerve, and thus represents the *secretory* and *sensory* (*afferent*) *roots* of the ganglion. The *sympathetic root* is formed by slender twigs from the plexus on the facial artery.

Branches.—Five or six small nerves descend from the ganglion to the submaxillary gland, and others run forwards to the mucous membrane of the mouth and Wharton's duct. The anterior branch of communication with the lingual nerve is probably composed of fibres which pass from the ganglion and are distributed with the offsets of that nerve. There is also occasionally a small branch or two passing to the hypoglossal nerve (Meckel, Bose).

A minute *sublingual ganglion* is described by some anatomists on the filaments passing from the lingual nerve to the sublingual gland (fig. 22; fig. 35, 8); and small groups of nerve-cells are also found in the adjoining part of the lingual trunk (Rauber). In some animals, groups of cells accompany the branches to the submaxillary gland and extend into its hilum (Langley).

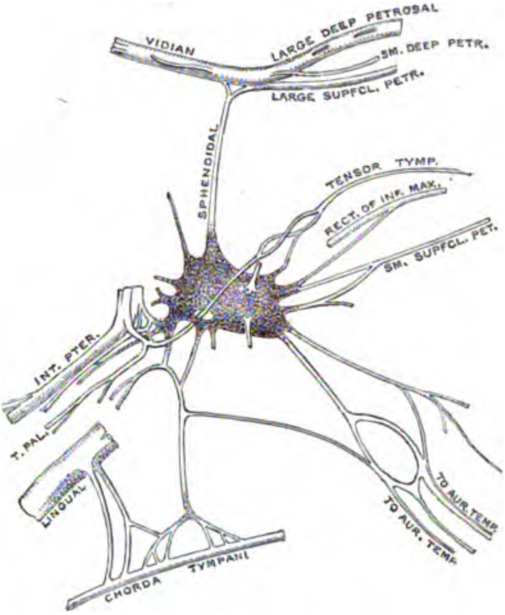


FIG. 23.—THE OTIC GANGLION, WITH ITS ROOTS AND BRANCHES. (Rauber.) $\frac{4}{1}$.

Otic ganglion.—The otic ganglion, or ganglion of Arnold, of a reddish-grey colour, is oval in shape, flattened from within out, and measures about 4 mm. in its longest (antero-posterior) diameter. It is situated immediately below the foramen ovale, on the deep surface of the mandibular nerve, covering, and not unfrequently surrounding, the origin of the internal pterygoid branch. Its inner surface is close to the cartilaginous part of the Eustachian tube and the tensor palati muscle; behind it is the middle meningeal artery. Its cells belong to the multipolar variety.

Roots.—The ganglion receives, through its connexion with the nerve to the internal pterygoid, fibres from the mandibular nerve, and these may be regarded as constituting its *secretory* and *sensory* (*afferent*) *roots* (*short root* of Arnold); the *sympathetic root* is a filament

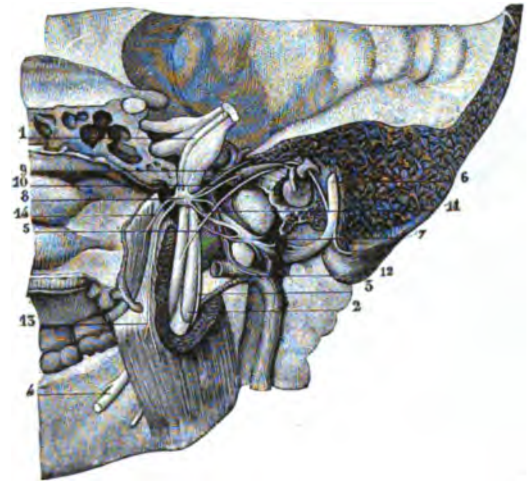


FIG. 24.—THE OTIC GANGLION AND ITS CONNEXIONS FROM THE INNER SIDE. (From Sappey, after Arnold.) $\frac{3}{5}$.

The temporal bone is divided so as to show the inner surface of the membrana tympani and the canal of the facial nerve; the foramen ovale is opened on the inner side: 1, small root of the fifth nerve, passing down on the inner side of the semilunar ganglion to unite with the mandibular division; 2, inferior dental nerve; 3, mylohyoid branch, seen also farther down emerging in front of the internal pterygoid muscle; 4, lingual; 5, chorda tympani; 6, facial nerve in its canal; 7, auriculo-temporal nerve, inclosing in its loop of origin the middle meningeal artery; 8, otic ganglion; 9, small superficial petrosal nerve; 10, branch to the tensor tympani muscle; 11, twig connecting the ganglion with the auriculo-temporal nerve; 12, twig to the ganglion from the sympathetic on the meningeal artery; 13, nerve to the internal pterygoid muscle; 14, branch to the tensor palati muscle.

(or two) passing forwards from the plexus on the middle meningeal artery. The ganglion is also joined posteriorly by the *small superficial petrosal nerve* (*long root*, Arnold), which connects it with, and probably conveys to it secretory fibres from, the facial and glossopharyngeal nerves (p. 38); and a slender *sphenoidal* filament ascends from it to the Vidian nerve.

Branches.—Secretory.—Two or more pale branches pass backwards to the roots of the auriculo-temporal nerve, and convey secretory fibres from the glossopharyngeal nerve to the parotid gland.

Communicating.—A twig descends to the chorda tympani, and slender filaments pass from the ganglion to the nerves supplying the internal pterygoid, tensor palati, and tensor tympani muscles. A filament also joins the buccal nerve (Rauber).

SUMMARY.—The mandibular nerve sends cutaneous filaments to ramify on the side of the head and the external ear, in the external auditory canal and membrana tympani, the lower lip, and the lower part of the face; sensory branches are supplied by it to the greater part of the tongue; and branches are furnished to the mucous membrane of the mouth, the lower teeth and gums, the salivary glands, the articulation of the lower jaw, the dura mater and skull and probably to part of the Eustachian tube.

The nerve supplies the muscles of mastication—viz. the masseter, temporal, and two pterygoids; also the mylohyoid, the anterior belly of the digastric, the tensor palati and the tensor tympani muscles.

SIXTH OR ABDUCENT NERVE.

The **sixth nerve** (*nervus abducens*) is distributed solely to the external rectus muscle of the eye. Its fibres arise mainly from a nucleus placed close to the floor of the fourth ventricle immediately above the striæ acusticæ, beneath the eminentia teres, but a few come from a small group of nerve-cells placed more deeply near the facial nucleus. Leaving at the inner side of the nucleus, the fibres pass forwards and somewhat downwards through the ventral part of the pons, and form a flattened band, which emerges at its lower edge immediately external to the pyramid. One or two of the innermost bundles may issue between the fibres of the pyramid, or above the lower edge of the pons.

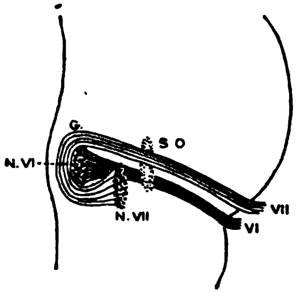


FIG. 25.—PLAN OF THE ORIGIN AND COURSE WITHIN THE PONS OF THE SIXTH AND SEVENTH NERVES. (G. D. Thane.)

The nerves and their nuclei are projected on to a sagittal section of the pons near the median plane: VI, sixth nerve; N.VI, its nucleus; VII, facial nerve; G., its inner genu; N.VII, its nucleus; S O, superior olive.

The nerve speedily becomes rounded, and is directed upwards, outwards, and slightly forwards, lying for a distance of about 15 mm. in the subarachnoid space between the anterior surface of the pons and the occipital bone. It then enters an aperture in the dura mater to the inner side of and slightly below that of the fifth nerve (see fig. 1), and passing on the outer side of the inferior petrosal sinus it crosses over the apex of the petrous bone, and beneath the petro-sphenoidal ligament to enter the cavernous sinus. In that cavity the nerve is directed forwards along the outer side of the internal carotid artery, and reaching the outer wall of the space anteriorly, it then passes into the orbit through the sphenoidal fissure, and between the heads of the external rectus, to which muscle it is distributed on its ocular surface (fig. 7, 6; fig. 14, 5). As the nerve enters the orbit, it is placed below the other nerves passing through the sphenoidal fissure, but above the ophthalmic veins.

While contained in the cavernous sinus, the sixth nerve is joined by filaments from the carotid plexus of the sympathetic, and as it enters the orbit it receives a small filament from the ophthalmic nerve.

The number of fibres in the sixth nerve has been estimated at 2,000 to 2,500 by Rosenthal, 3,600 by Tergast. They are mostly large, but there are some of medium size; fine fibres are scanty.

Variety.—Absence of the sixth nerve upon one side is recorded, its place being supplied by a branch of the third nerve (Generali).

SEVENTH OR FACIAL NERVE.

The **seventh** (*nervus facialis*) is a mixed nerve consisting of a large motor and a smaller sensory portion. The *motor* part arises from a nucleus which is situated in the formatio reticularis of the lower part of the pons, about on the same level as the main nucleus of the sixth nerve, but farther from the floor of the fourth ventricle. The fibres leave the back of the nucleus, and are directed at first dorso-mesially towards the lower end of the abducent nucleus. Here they are collected into a well-marked bundle, which ascends for a short distance close beneath the floor of the ventricle, then bends sharply downwards and outwards over the upper end of the abducent nucleus (*inner genu of the facial nerve*), and finally runs forwards and outwards through the lower part of the pons, to emerge at the upper end of the medulla oblongata in the depression between the olivary and restiform bodies.

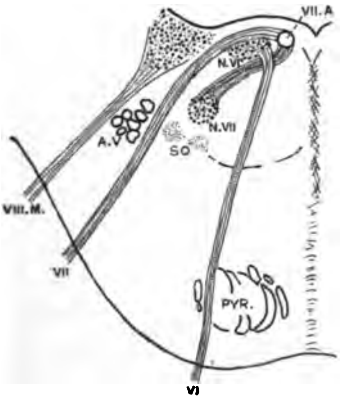


FIG. 26.—PLAN OF THE ORIGINS OF THE SIXTH AND MOTOR ROOT OF THE SEVENTH CEREBRAL NERVES. (G. D. Thane; adapted from Schwalbe.)

The outline represents a transverse section of the lower part of the pons, on to which the course of the facial nerve is projected; VI, sixth nerve; N.VI, its nucleus; VII, facial nerve; VII.A, the ascending portion of its root, supposed to be seen in optical section; N.VII, its nucleus; SO, superior olive; A.V, sensory or bulbo-spinal root of fifth nerve; VIII.M., mesial root of acoustic nerve.

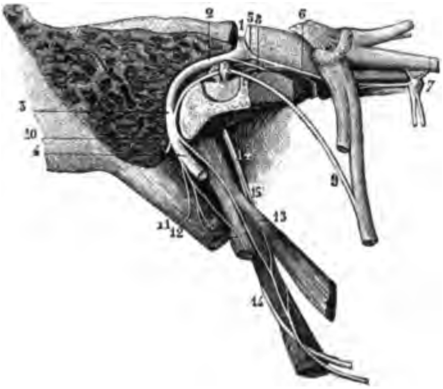


FIG. 27.—THE FACIAL NERVE IN ITS CANAL, WITH ITS CONNECTING BRANCHES, ETC. (From Sappey, after Hirschfeld and Leveillé.) $\frac{3}{5}$.

The mastoid and a part of the petrous bone have been divided nearly vertically, and the canal of the facial nerve opened in its whole extent from the internal meatus to the stylomastoid foramen; the Vidian canal has also been opened from the outer side: 1, facial nerve in the first horizontal part of its course; 2, its second part turning backwards; 3, its vertical portion; 4, the nerve at its exit from the stylomastoid foramen; 5, geniculate ganglion; 6, large superficial petrosal nerve; 7, sphenopalatine ganglion; 8, small superficial petrosal nerve; 9, chorda tympani; 10, posterior auricular branch cut short; 11, branch to the digastric muscle; 12, branch to the stylohyoid muscle; 13, twig uniting with the glossopharyngeal nerve (14 and 15).

The *sensory portion* arises from the geniculate ganglion situated on the knee-shaped bend of the facial as it lies in the facial canal (aqueduct of Fallopius). The central processes of its ganglionic cells pass inwards with the motor portion of the facial as far as the internal auditory meatus, and then separate as the *pars intermedia*, or *nerve of Wrisberg*, which is attached to the surface of the brain between the acoustic nerve and the motor portion of the facial. Its fibres turn down in the upper part of the fasciculus solitarius of the medulla oblongata, and end in the grey matter which adjoins this bundle (nucleus of solitary bundle). Some of its peripherally directed fibres pass directly from the ganglion as the *great superficial petrosal*, the others are closely associated with the motor portion of the facial nearly as far as the stylomastoid foramen, where they leave it as the *chorda tympani* nerve.

The fibres of the facial nerve are mostly of medium size, but the pars intermedia consists almost wholly of very small fibres. Appearances which seem indicative of a degenerated ganglion are seen in the facial nerve close to its exit from the bulb (Thomsen, Gaskell).

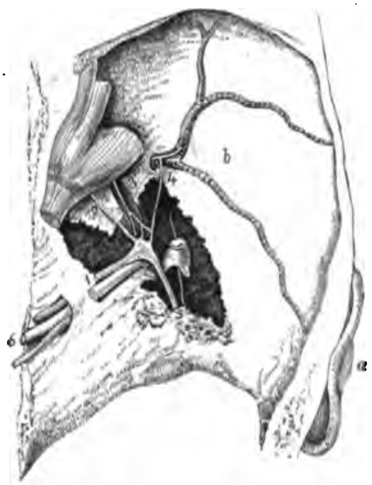


FIG. 28.—GENICULATE GANGLION OF THE FACIAL NERVE AND ITS CONNEXIONS FROM ABOVE. (Bidder.)

The dissection is made in the middle fossa of the skull on the right side, part of the temporal bone being removed so as to open the internal auditory meatus, hiatus Fallopii, and a part of the canal of the facial nerve, together with the cavity of the tympanum: *a*, auricle; *b*, middle fossa of the skull with the meningeal artery ramifying in it; 1, facial and acoustic nerves in the internal auditory meatus; 2, large superficial petrosal nerve; 3, small superficial petrosal nerve lying over the tensor tympani muscle; 4, external superficial petrosal nerve joining sympathetic twig on the meningeal artery; 5, facial and chorda tympani; 6, nerves entering the jugular foramen.

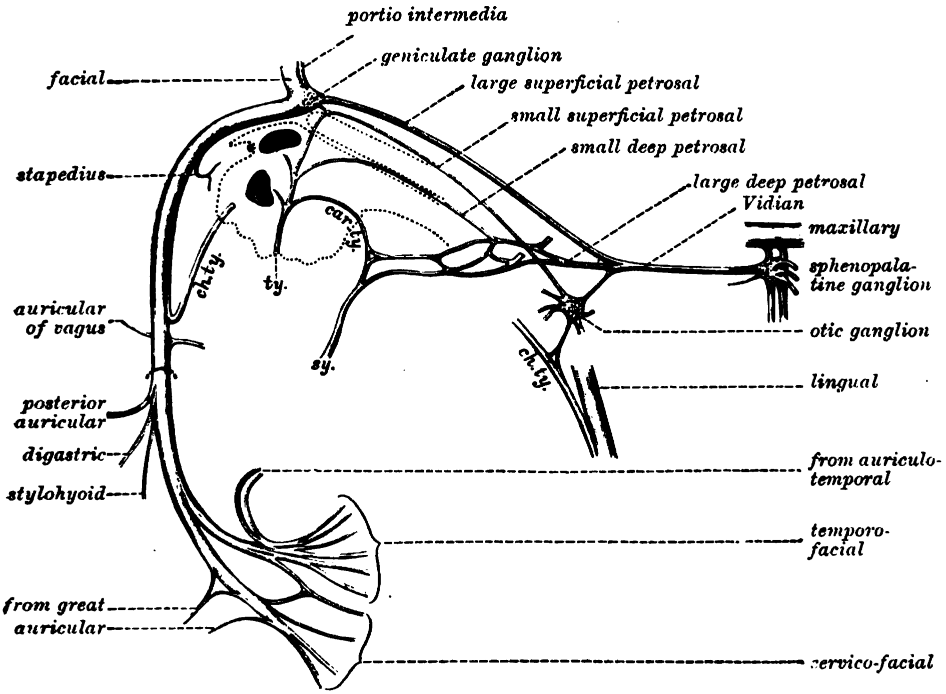
From their superficial attachments to the pons the two portions of the facial nerve are directed outwards across the subarachnoid space in company with the acoustic nerve to the internal auditory meatus. Here the facial lies in a groove along the upper and fore part of the acoustic nerve, and the pars intermedia is placed between the two. At the bottom of the meatus the facial nerve enters the canalis facialis (aqueduct of Fallopius), and follows the windings of that canal through the temporal bone to the lower surface of the skull. It passes at first horizontally outwards and forwards for a short distance, between the cochlea and vestibule, to the inner wall of the tympanum, where it makes a sharp bend and goes straight back in the inner wall of the tympanum for about 10 mm. In this part of its course it is separated from the tympanic cavity by a thin plate of bone, and lies above the fenestra vestibuli and below the external semicircular canal. It then turns downwards and a little outwards for about 15 mm. behind the tympanic cavity, and emerges from the temporal bone at the stylomastoid foramen. Below the skull, the facial trunk is continued downwards and forwards through the substance of the parotid gland; and a little behind the ramus of the lower jaw it terminates by dividing into two parts, *temporo-facial* and *cervico-facial*, from which numerous branches spread over the side of the head, the face, and the upper part of the neck, communicating freely with one another, and thus forming a radiating plexus to which the name of *pes anserinus* or *plexus parotideus* has been given.

Branches.—Sensory.—These all arise from the nerve in its course within the temporal bone.

Communicating filaments with the acoustic nerve.—These are one or two slender twigs passing between the geniculate ganglion and the upper division of the eighth nerve at the bottom of the internal auditory meatus.

The large superficial petrosal nerve.—This nerve has already been described (p. 21) in connexion with the roots of the sphenopalatine ganglion. In all probability it is distributed through this ganglion to the mucous membrane of the posterior part of the palate.[1]

Communication with the small superficial petrosal nerve.—A minute branch connects the geniculate ganglion with the small superficial petrosal nerve passing from the tympanic plexus to the otic ganglion (fig. 29).


portio intermedia
geniculate ganglion
large superficial petrosal
small superficial petrosal
small deep petrosal
large deep petrosal
Vidian
maxillary
sphenopalatine ganglion
otic ganglion
lingual
from auriculo-temporal
temporo-facial
cervico-facial
facial
stapedius
auricular of vagus
posterior auricular
digastric
stylohyoid
from great auricular
ch.ty.
ty.
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sy.
ch.ty.

FIG. 29.—PLAN OF THE FACIAL NERVE, WITH SOME OF ITS COMMUNICATIONS. (G. D. Thane.)
ch.ty., chorda tympani: its middle part is removed; *ty.*, tympanic branch of the glossopharyngeal; *sy.*, sympathetic on the internal carotid artery; *car.ty.*, carotico-tympanic nerve, passing between the tympanic nerve and the sympathetic in the carotid canal.

The *external superficial petrosal nerve* (Bidder) unites the geniculate ganglion with the sympathetic filaments on the middle meningeal artery. This nerve is not always present (Rauber).

Chorda tympani.—This branch leaves the facial nerve at the lower end of the facial canal, and is directed upwards and forwards through a small canal (*iter chordæ posterius*) which opens on the posterior wall of the tympanum, close to the attachment of the tympanic membrane. It then arches forwards, being invested by the mucous lining of the cavity, across the upper part of the membrane and over the inner side of the handle of the malleus, above the insertion of the tensor tympani muscle. Finally, leaving the cavity by an aperture (*iter chordæ anterius*) at the inner end of the Glaserian fissure, the nerve inclines downwards on the mesial side of the internal lateral ligament of the jaw, and unites at an acute angle with the lingual nerve, in which its fibres are continued to the submaxillary ganglion and the tongue. Before joining the lingual nerve, the chorda receives a communicating filament from the otic ganglion.

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[1] A. F. Dixon, Journ. Anat. and Phys. xxxiii.

Motor branches.—A branch to the stapedius muscle is given off by the facial nerve as it lies in the vertical portion of the facial canal.

A *communication with the auricular branch of the vagus nerve* is generally present, in the form of a twig leaving the facial nerve close above the stylomastoid foramen.

The *posterior auricular nerve* arises close to the stylomastoid foramen, and turns upwards between the ear and the mastoid process, where it divides into auricular and occipital branches.

The *auricular branch* ascends behind the ear and is distributed to the posterior auricular and the small muscles on the cranial surface of the pinna. A twig is sometimes continued upwards to the superior auricular muscle.

The *occipital branch* is directed backwards close to the bone, and supplies the posterior part of the occipito-frontalis muscle.

The posterior auricular nerve receives communications from the great auricular and small occipital nerves of the cervical plexus, as well as from the auricular branch of the vagus, and certain filaments which may sometimes be followed from its branches to the skin are probably composed of fibres derived from these nerves.

The *digastric branch* arises close below the preceding nerve, and divides into two or three filaments which enter the posterior belly of the digastric muscle; one of these sometimes passes through or above the digastric, and joins the glossopharyngeal nerve near the base of the skull.

The *stylohyoid branch*, long and slender, arises in common with the digastric branch, and inclines forwards to enter the stylohyoid muscle on its posterior aspect.

TEMPORO-FACIAL DIVISION.—The temporo-facial, the larger of the two primary divisions of the facial nerve, is directed forwards through the upper part of the parotid gland, crossing over the external carotid artery and the temporo-maxillary vein. It receives one or two considerable offsets from the auriculo-temporal nerve (p. 26), and speedily divides into a number of branches which form, by their communications with one another and with branches of the fifth nerve, a network over the side of the face, extending as high as the temple and as low as the mouth. Its ramifications are arranged in temporal, zygomatic, and buccal sets.

The *temporal branches* ascend over the zygoma and supply the anterior and superior auricular muscles, the frontalis, the upper part of the orbicularis palpebrarum, and the corrugator supercilii. One or two filaments pass to the auricle, and are distributed to the small muscles on its outer surface. These branches form communications with the auriculo-temporal nerve, the temporal branch of the maxillary, and the supra-orbital and lacrymal branches of the ophthalmic nerve.

The *zygomatic branches* (*malar*) cross the zygomatic (malar) bone to reach the outer side of the orbit and supply the orbicular muscle. Some filaments are distributed to both the upper and lower eyelids: those in the upper lid join filaments from the supra-orbital nerve, and those in the lower lid are connected with filaments from the infra-orbital nerve. Filaments from this part of the facial also communicate with the facial division of the zygomatic branch of the maxillary nerve.

The *buccal branches* (*infra-orbital*), of larger size than the others, are almost horizontal in direction, and are distributed between the orbit and mouth. They supply the buccinator and orbicularis oris muscles, the zygomatici, the elevators of the upper lip and angle of the mouth, and the muscles of the nose. Beneath the elevator of the upper lip these nerves are united in a plexus with the terminal branches of the maxillary nerve; on the side of the nose they communicate with the naso-ciliary, and at the inner angle of the orbit with the infratrochlear nerve. The lower branches of this set are connected with those of the cervico-facial division.

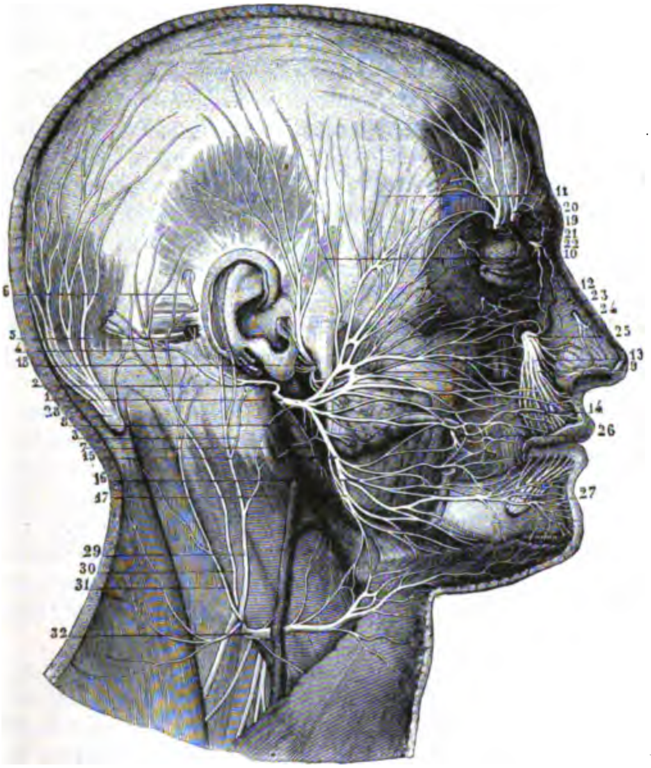

Fig. 30.—Superficial distribution of the facial, trigeminal, and other nerves of the head. (From Sappey, after Hirschfeld and Leveillé.) $\frac{3}{5}$.

Facial Nerve.—1, trunk of the facial nerve after its exit from the stylomastoid foramen; 2, posterior auricular branch; 3, filament of the great auricular nerve uniting with the foregoing; 4, occipital branch; 5, auricular branch; 6, twig to the superior auricular muscle; 7, nerve to the digastric; 8, that to the stylohyoid muscle; 9, superior or temporo-facial division of the nerve; 10, 11, temporal branches; 12, malar; 13, 14, buccal; 15, inferior or cervico-facial division of the nerve; 16, mandibular; 17, cervical branch.

Fifth Nerve.—18, auriculo-temporal uniting with the facial, giving anterior auricular and parotid branches, and ascending to the temporal region; 19, 20, supra-orbital; 21, lacrymal; 22, infra-trochlear; 23, facial twig of the zygomatic; 24, superficial branch of the naso-ciliary; 25, infra-orbital; 26, buccal, uniting with branches of the facial; 27, mental.

Cervical Nerves.—28, great occipital; 29, great auricular; 30, 31, small occipital; 32, superficial cervical.

Cervico-facial division.—This division of the facial nerve is directed obliquely through the parotid gland towards the angle of the lower jaw, and gives branches to the face below those of the preceding division, and to the upper part of the neck. The branches are named mandibular and cervical. In the gland, this division of the facial nerve is joined by filaments of the great auricular nerve of the cervical plexus, and offsets from it penetrate the substance of the gland.

The *mandibular branch* (*ramus marginalis mandibulæ*), sometimes double, runs forwards beneath the depressor anguli oris, and, after communicating with the mental branch of the inferior dental nerve, supplies the muscles of the lower lip. One superficial branch is continued along the margin of the lower jaw to the chin.

The *cervical branch* (*ramus colli*) perforates the deep cervical fascia and divides into slender offsets, which form arches beneath the platysma as low as the hyoid bone. They supply the platysma, and form one or two loops of communication with the upper division of the superficial cervical nerve.

SUMMARY.—The facial nerve is the principal motor nerve of the head, supplying all the superficial, and some of the deep muscles. Its superficial offsets are distributed to the muscles of the scalp, the muscles of the external ear, nose, mouth, and eyelids (with the exception of the levator palpebræ superioris), and to the cutaneous muscle of the neck (platysma). Of the deep muscles, it supplies the stapedius, stylohyoid, and posterior belly of the digastric (according to some also the levator palati and azygos uvulæ muscles through the large superficial petrosal nerve). It also furnishes, through its sensory portion, sensory fibres to the palate, and taste-fibres to the anterior two-thirds of the tongue. Secretory and vaso-dilator fibres for the submaxillary and sublingual glands may also be derived from the facial.

The facial nerve is freely connected with the three divisions of the fifth nerve; and it also has communications with the sphenopalatine, submaxillary, and otic ganglia, with the acoustic, glossopharyngeal, and vagus nerves (through the auricular branch of the latter), and with parts of the sympathetic and spinal nerves.

Filaments which may be traced from the branches of the facial nerve to the skin of the face and neck are doubtless derived from the communications with sensory nerves, especially the auriculo-temporal, great auricular, and superficial cervical.

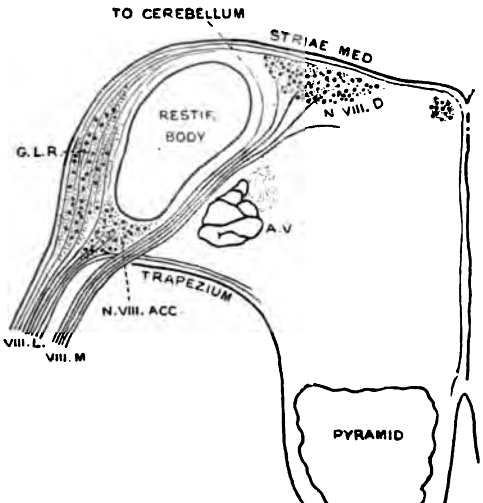

FIG. 31.—PLAN OF THE ROOTS OF THE ACOUSTIC NERVE. (G. D. Thane.)

The outline represents a section at the junction of the bulb with the pons: VIII.M., vestibular division; VIII.L., cochlear division of the auditory nerve; N.VIII.ACC., accessory nucleus; G.L.R., lateral nucleus (acoustic tubercle); N.VIII.D., dorsal nucleus; A.V, bulbo-spinal root of the fifth nerve.

EIGHTH OR ACOUSTIC NERVE.

The **eighth,** or **nervus acusticus** (*auditory nerve*), consists of two portions—cochlear and vestibular — which differ from one another in their peripheral endings, central connexions, period of medullation, and functions.

The *cochlear division* arises from the spiral ganglion of the cochlea, situated near the inner edge of the osseous spiral lamina. The cells of this ganglion are bipolar, and their peripheral processes are distributed to the organ of Corti, while the central ones pass down the modiolus and then through the opening of its central canal or through the foramina on the *tractus spiralis foraminosus* into the outer end of the internal auditory meatus. Here they join the vestibular division, and the common trunk passes along the meatus and almost directly inwards across the subarachnoid space towards the restiform body. The common trunk is about 15 mm. long, and lies in front of the cerebellum, just above the flocculus; it has the facial nerve above and the petrous part of the temporal bone in front. The fibres of the cochlear division end in the acoustic tubercle and in the accessory or ventral nucleus, which form the central sensory nuclei for audition. The fibres which pass over the restiform body and appear on the floor of the fourth ventricle as the striæ acusticæ, are derived from the cells of the acoustic tubercle. These turn inwards at the middle line and pass through the raphe to the opposite side.

The *vestibular division* arises from a group of bipolar cells (*vestibular ganglion, ganglion of Scarpa*) placed at the upper part of the outer end of the internal auditory meatus. This ganglion is connected peripherally by an upper branch with the utricle and the superior and external semicircular canals, and by a lower branch with the saccule and the posterior semicircular canal. The central fibres pass, as already stated, with the cochlear division towards the restiform body, where they are situated to the ventral side of the cochlear fibres. They enter the medulla oblongata, and pass between the restiform body and the bulbo-spinal root of the fifth nerve towards the floor of the fourth ventricle, near which they end by arborising among the cells of the vestibular nucleus. (For the details of the termination of these nerve-fibres the reader is referred to Vol. III. Part I.)

The peripheral connexions of the ganglia of the acoustic nerve, and the apertures by which they leave the meatus, are shown in the following table:

Cochlear nerve .	Spiral ganglion .	Tractus spiralis foraminosus and foramen centrale cochleæ.		
Vestibular nerve .	Vestibular ganglion	Upper division.	Utricular nerve Superior ampullary nerve External ampullary nerve	Area cribrosa superior.
		Lower division.	Saccular nerve	Area cribrosa media.
			Posterior ampullary nerve	Foramen singulare.

This table is based upon the observations of G. L. Streeter[1] and differs from those of W. His, jun.,[2] who considered that the nerves to the saccule and posterior ampullæ belong to the cochlear division of the nerve.

NINTH OR GLOSSOPHARYNGEAL NERVE.

The **glossopharyngeal** is a mixed nerve, and its motor and sensory fibres at their attachment to the upper part of the medulla oblongata do not form two distinct and independent roots, but consist of five or six filaments arranged in a vertical line immediately below the facial and above the vagus nerves and a little external to the olive.

The motor fibres arise from a small column of nerve-cells situated at the upper end of the ventral motor nucleus of the vagus and immediately below the motor nucleus of the facial. The sensory fibres arise from the cells of two ganglia (jugular and petrosal), which in their structure resemble spinal ganglia.

The **jugular ganglion** (*g. superius*) is situated at the upper part of the osseous groove in which the nerve lies during its passage through the jugular foramen. It is from 1 to 2 mm. in length, and it includes only the lower filaments of the nerve, the upper ones forming a separate fasciculus which passes over the ganglion, and joins the trunk of the nerve below it.[3]

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[1] Verhand. der anat. Gesellschaft, Genf, 1905.

[2] Arch. f. Anat. 1889.

[3] This ganglion is not always present in the embryo, and may cease to grow at an early stage, so as to be very rudimentary in the adult (G. C. Streeter, American Journal of Anatomy, iv. No 2).

The **petrosal ganglion** is contained in a small depression at the lower end of the groove in the petrous part of the temporal bone, and measures from 4 to 5 mm. in length. From it arise the small branches by which the glossopharyngeal is connected with other nerves at the base of the skull; these are the tympanic nerve, and the branches of communication with the vagus and sympathetic.

The central processes connected with the cells of these two ganglia pass with the fibres of the motor root through the middle compartment of the jugular foramen, along with the vagus and accessory, but the glossopharyngeal occupies a separate opening in the dura mater. In its course through the subarachnoid space the nerve lies in front of the flocculus and above the vagus. On reaching the medulla oblongata the sensory fibres traverse its substance to reach the fasciculus solitarius, and divide into two branches, a short upper and a much longer lower one. The descending fibres form a part of the fasciculus solitarius, and end in relation to the neighbouring grey matter. Below the jugular and petrous ganglia the peripheral processes of their cells form with the motor root a common trunk which appears between the internal carotid artery and the jugular vein, and is directed downwards over the carotid artery and beneath the styloid process and the muscles connected with it, to the hinder border of the stylopharyngeus; then curving gradually forwards, it crosses over the outer surface of the latter muscle, and passes beneath the hyoglossus to end in branches for the hinder part of the tongue (fig. 33, 16).

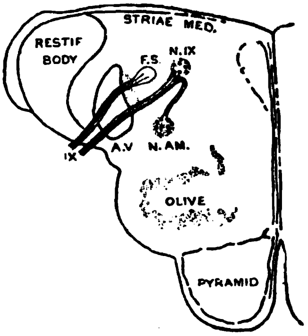

FIG. 32.—PLAN OF THE ORIGIN OF THE GLOSSOPHARYNGEAL NERVE. (After Obersteiner.)

The outline represents a transverse section of the upper end of the bulb: IX, roots of the glossopharyngeal nerve; F.S., fasciculus solitarius; N.IX, glossopharyngeal nucleus; N.AM., nucleus ambiguus; A.V, bulbo-spinal root of the fifth nerve.

A filament unites the petrosal ganglion of the glossopharyngeal nerve with the upper cervical ganglion of the sympathetic; a second passes to the auricular branch of the vagus; and a third, which however is not constant, joins the ganglion of the root of the vagus nerve.

The glossopharyngeal nerve is also joined below the petrosal ganglion, in many cases, by a communicating branch from the facial nerve (p. 34).

A branch is furnished to the *stylopharyngeus* muscle, and it is probable that filaments are also distributed to the middle constrictor of the pharynx.

The *tympanic branch* (nerve of Jacobson) ascends from the petrosal ganglion, in company with the tympanic branch of the ascending pharyngeal artery, through a small canal, the orifice of which is seen on the ridge of bone between the jugular fossa and the carotid foramen. Having gained the inner wall of the tympanum, the nerve runs upwards and forwards in a groove on the surface of the promontory, and, after giving (or receiving) several branches, leaves the cavity at its upper and fore part, where it becomes the *small superficial petrosal nerve*. The latter traverses a small canal, which crosses beneath the upper end of the canal of the tensor tympani muscle, and emerges on the upper surface of the petrous portion of the temporal bone, immediately external to the hiatus Fallopii. Then inclining downwards, the nerve passes from the skull through the fissure between the petrous and the great wing of the sphenoid, or occasionally through a small aperture in the latter bone, and terminates in the otic ganglion. As it lies in its canal, the small superficial petrosal nerve is joined by a filament of communication from the geniculate ganglion of the facial nerve, or from the large superficial petrosal nerve close to that ganglion.

The branches of the tympanic nerve are partly distributed to the mucous lining of the middle ear, and partly form communications with other nerves, giving rise to what is called the *tympanic plexus.* Of the former set, the principal branches are—one directed forwards to the Eustachian tube, and two backwards to the neighbourhood of the fenestra cochleæ and fenestra vestibuli, and to the mastoid cells. The communicating branches are, in addition to the small superficial petrosal nerve with its filament of union with the facial, one or two twigs (*carotico-tympanic*) which pass downwards and forwards through the anterior wall of the tympanum to the carotid canal and join the sympathetic on the carotid artery, and the *small deep petrosal nerve* which runs forwards in a minute canal in the substance of the processus cochleariformis and enters the foramen lacerum, where it joins the carotid plexus of the sympathetic, or sometimes one of the large petrosal nerves (figs. 23, 29).

The tympanic nerve while in its canal is surrounded by a small fusiform mass of soft vascular tissue which has been called the *tympanic gland* (Krause); and as it lies in the tympanum it contains numerous nerve-cells in irregular groups.

Pharyngeal branches. — The largest of these (carotid branch, pharyngeal division of the glossopharyngeal nerve, Henle) descends along the internal carotid artery and unites with the pharyngeal branch of the vagus to form the pharyngeal plexus (p. 43); this branch is sometimes divided into two or even three parts. One or two smaller twigs pass inwards through the superior constrictor muscle, and supply the mucous membrane of the upper part of the pharynx.

Tonsillar branches.—Slender filaments pass from the glossopharyngeal nerve, as it approaches the base of the tongue, to the tonsil, over which they form a sort of plexus (circulus tonsillaris), to the soft palate, and to the pillars of the fauces.

Lingual branches.—The glossopharyngeal nerve divides as it passes beneath the hyoglossus muscle into two parts. One turns to the upper surface of the tongue and subdivides into many branches, which supply the circumvallate papillæ and the mucous membrane over the posterior third of the organ, the hindmost filaments reaching the anterior surface of the epiglottis. The other is smaller, and is distributed to the mucous membrane of the side of the tongue, extending to about the middle of its length, where it forms a communication with the lingual nerve. Beneath the mucous membrane the terminal filaments are united in a plexus which contains microscopic ganglia.

Variety.—In one case a branch from the glossopharyngeal supplied the mylohyoid muscle and the anterior belly of the digastric, the normal mylohyoid nerve being wanting.[1]

SUMMARY.—The glossopharyngeal nerve distributes branches to the mucous membrane of the posterior third of the tongue, to the pharynx, and to the middle ear, as well as to the stylopharyngeus muscle, and possibly also to the middle constrictor of the pharynx. Its branches to the tongue contain fibres for common sensation and for taste. By its small superficial petrosal branch it furnishes secretory and vaso-dilator fibres (through the otic ganglion and the auriculo-temporal nerve) to the parotid gland. It is connected with the following nerves—viz. the mandibular division of the fifth (through the otic ganglion), the facial, the vagus (its trunk and branches), and the sympathetic.

The glossopharyngeal is composed almost entirely of very fine fibres, but mixed with these there are a few of medium size.

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[1] Guy's Hosp. Reports, xiv. 453.

TENTH OR VAGUS NERVE.

The **tenth** or **vagus** (*pneumogastric*) nerve is much larger than the glossopharyngeal, and has the longest course of all the cerebral nerves, extending through the neck and thorax to the upper part of the abdomen. It resembles the glossopharyngeal in containing both sensory and motor fibres, which are mixed with one another at their apparent origin from the brain. The *motor* fibres arise from two columns of nerve-cells in the medulla oblongata—a *dorsal* composed of small cells, and a *ventral* formed by large cells; the ventral is usually termed the *nucleus ambiguus*. The sensory fibres arise from two ganglia

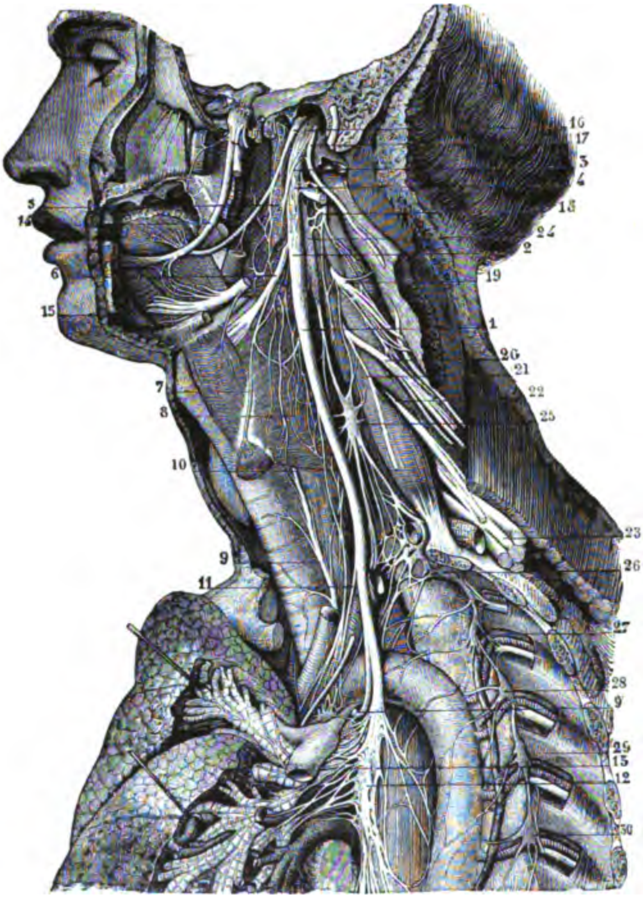

FIG. 33.—THE DISTRIBUTION AND CONNEXIONS OF THE VAGUS NERVE ON THE LEFT SIDE IN THE NECK AND UPPER PART OF THE THORAX. (From Sappey, after Hirschfeld and Leveillé.) ⅓.

1, vagus nerve; 2, ganglion of its trunk; 3, bulbar part of the accessory; 4, union of the vagus with the hypoglossal; 5, pharyngeal branch of the vagus; 6, superior laryngeal nerve; 7, external laryngeal; 8, communication of the external laryngeal nerve with the superior cardiac branch of the sympathetic; 9, recurrent or inferior laryngeal; 10, superior, and 11, inferior cervical cardiac branches; 12, 13, posterior pulmonary plexus; 14, lingual branch of the mandibular nerve; 15, distal part of the hypoglossal nerve; 16, glossopharyngeal nerve; 17, accessory nerve, uniting by its inner branch with the vagus, and by its outer passing into the sternomastoid muscle; 18, second cervical nerve; 19, third; 20, fourth; 21, origin of the phrenic nerve; 22, 23, fifth, sixth, seventh, and eighth cervical nerves, forming with the first thoracic the brachial plexus; 24, superior cervical ganglion of the sympathetic; 25, middle cervical ganglion; 26, inferior cervical ganglion united with the first thoracic ganglion; 27, 28, 29, 30, second, third, fourth, and fifth thoracic ganglia.

situated outside the cranial cavity. The nerve-cells of both ganglia belong to the unipolar or spinal type.

The **upper ganglion** or **ganglion of the root** of the vagus nerve (*ganglion jugulare*), situated in the jugular foramen, is of a greyish colour, nearly spherical, and about 4 mm. in diameter. It has filaments connecting it with other nerves—viz. with the facial, the petrosal ganglion of the glossopharyngeal, the accessory, and the sympathetic.

The **lower ganglion** or **ganglion of the trunk** of the vagus nerve (cervical ganglion, *ganglion nodosum*) is placed below the base of the skull, about 1 cm. beyond the upper ganglion. It is of a flattened cylindrical form and reddish colour, and measures from 15 to 20 mm. in length and 4 mm. in breadth. The bulbar part of the accessory nerve runs over the surface of the ganglion, and is in part continued directly into the pharyngeal and superior laryngeal branches of the vagus; some of the accessory fibres, however, become incorporated with the main trunk, and enter the inferior laryngeal and cardiac branches. The lower ganglion communicates with the hypoglossal, the spinal, and the sympathetic nerves.

The central processes of these ganglion-cells pass upwards to the jugular foramen, which they traverse with the glossopharyngeal and accessory nerves, and then pierce the dura mater by the same opening as the latter nerve. In the cranial cavity they cross inwards, mixed with the motor fibres, to the side of the medulla oblongata, forming a flattened band about 15 mm. in length. These nerve-roots lie between the occipital bone in front and the choroid plexus of the lateral recess of the fourth ventricle and the flocculus behind, and are attached to the medulla oblongata by twelve to fifteen filaments beginning close below, and continuing the line of, the roots of the glossopharyngeal nerve. In the medulla oblongata the sensory fibres form a large part of the fasciculus solitarius, and end in relation with its nuclei.

The fibres of the vagal roots are mostly small. In the trunk of the nerve there are also numerous fibres of medium size, but these are probably derived in large part from the bulbar portion of the accessory nerve, which joins the vagus close below the skull. Many of the larger fibres are continued into the pharyngeal and inferior laryngeal branches, which are in great measure distributed to striped muscles.

The trunk of the vagus descends in the neck between, and concealed by, the internal jugular vein and the internal carotid artery, and afterwards similarly between the vein and the common carotid artery, being enclosed along with them in the sheath of the vessels. In their passage into and through the thorax, the nerves are disposed differently on the right and left sides.

On the right side the nerve crosses over the first part of the right subclavian artery at the root of the neck, and its recurrent laryngeal branch turns backwards and upwards round that vessel. The nerve then enters the thorax behind the right innominate vein, and descends on the side of the trachea to the back of the root of the lung, where it spreads out in the posterior pulmonary plexus. It emerges from this plexus in the form of two cords, which are directed to the œsophagus, and by their union and subdivision on it form, with similar branches of the left nerve, the œsophageal plexus. Near the lower part of the thorax, the branches of the nerve, which have thus interchanged fibres with the nerve of the left side, are gathered again into a single trunk, which, descending through the diaphragm along the back of the œsophagus, is finally divided between the posterior surface of the stomach and the cœliac plexus.

On the left side the vagus nerve, entering the thorax between the left carotid and subclavian arteries and behind the left innominate vein, crosses over the arch of the aorta, below which its recurrent laryngeal branch turns inwards and upwards. It then passes behind the root of the left lung, forming, like its fellow, a posterior pulmonary plexus, whence it descends along the œsophagus, and takes part in the formation of the œsophageal plexus. Inferiorly, it forms a single trunk in front of the œsophagus, and is spread out on the anterior surface of the stomach.

There are various circumstances in the distribution of the vagus nerves which at first sight appear anomalous, but which are explained by reference to the process of development. The recurrent direction of the inferior laryngeal branches arises from the extreme shortness or rather absence of the neck in the embryo at first, and from the primitive arterial arches having originally occupied a position at a higher level than the parts in which those branches are ultimately distributed, and having dragged them down as it were in the descent of the heart from the neck to the thorax. The recurrent direction may therefore be accepted as evidence of the development of those nerves before the occurrence of that descent. The passage of one recurrent laryngeal nerve round the subclavian artery, and of the other round the aorta, arises from the originally symmetrical disposition in which the innominate and subclavian arteries on the right side, and the arch of the aorta on the left, are derived from corresponding arches. The supply of the back of the stomach by the right vagus nerve, and of the front by the left nerve, is connected with the originally symmetrical condition of the alimentary canal, and the turning over of the stomach on its right side in its subsequent growth.

Some of the branches of the vagus serve to connect this with other nerves, but the larger number are distributed to various parts of the circulatory, respiratory, and digestive systems. The special connecting branches arise from the two ganglia of the nerve. The branches of distribution arise from the nerve in the several stages of its course as follows: In the jugular foramen, one small branch is given to the dura mater, and another to the ear; in the neck, branches are furnished successively to the pharynx, the larynx, and the heart; in the thorax, additional branches are supplied to the heart, as well as offsets to the pericardium, lungs, and œsophagus; and in the abdomen, its terminal branches are distributed to the stomach, liver, and other organs.

The upper ganglion of the vagus nerve receives a twig from the superior cervical ganglion of the sympathetic; one or two filaments pass between it and the accessory nerve; and there is sometimes a filament connecting it with the petrosal ganglion of the glossopharyngeal.

The lower ganglion of the vagus forms connexions with the hypoglossal nerve, with the superior cervical ganglion of the sympathetic, and with the loop between the first two cervical nerves.

The *recurrent* or *meningeal branch* arises from the upper ganglion of the vagus, and passes backwards through the jugular foramen to be distributed to the dura mater in the posterior fossa of the base of the skull.

The *auricular branch* (nerve of Arnold) is given off from the ganglion of the root, and, after receiving a filament from the petrosal ganglion of the glossopharyngeal nerve, runs backwards along the outer boundary of the jugular foramen to an opening near the root of the styloid process. It then traverses the substance of the temporal bone, crosses the facial canal on its inner side about 4 mm. from the lower end, forming here a communication with the facial nerve, and finally emerges between the external auditory meatus and the mastoid process, where it divides into two parts, one of which joins the posterior auricular nerve, while the other is distributed to the skin of the back of the pinna, and the lower and back part of the auditory canal.

Varieties.—In rare instances, absence of the auricular branch has been observed, or of the communication with the facial nerve. The auricular branch occasionally passes entirely into the facial trunk, and in that case its fibres are probably conveyed to the external ear through the posterior auricular nerve.

The *pharyngeal branch*, often represented by two or even more offsets, and composed mainly of fibres prolonged from the bulbar part of the accessory nerve, leaves the upper part of the ganglion of the trunk of the vagus. It courses inwards over the internal carotid artery, and divides into branches which, conjointly with those derived from the glossopharyngeal and the sympathetic, form the *pharyngeal plexus*. This plexus often contains one or more small ganglia, and from it filaments pass to the muscles and mucous membrane of the pharynx. The motor fibres are conveyed to the plexus by the pharyngeal branch of the vagus, but they are probably derived from the bulbar part of the accessory nerve (see p. 48); the levator palati and azygos uvulæ muscles are also supplied by a branch from this source.[1] One slender branch (*lingual branch of the vagus*, Luschka) descends from the pharyngeal plexus, receiving its fibres from the pharyngeal branches of both the glossopharyngeal and vagus nerves, and joins the hypoglossal nerve as that turns round the occipital artery.

Superior laryngeal nerve.—This branch springs from the middle of the ganglion of the trunk of the vagus, and inclines forwards on the inner side of the internal carotid artery towards the larynx. It is joined by filaments from the upper cervical ganglion of the sympathetic and from the pharyngeal plexus, and speedily divides into two branches which are distinguished as external and internal laryngeal.

The *external laryngeal branch*, the smaller of the two, runs downwards and forwards beneath the depressor muscles of the hyoid bone to the crico-thyroid muscle, in which it ends. It receives a filament from the upper cervical ganglion of the sympathetic, and it gives off twigs to the inferior constrictor muscle of the pharynx, as well as generally a cardiac branch which joins the superior cardiac branch of the sympathetic.

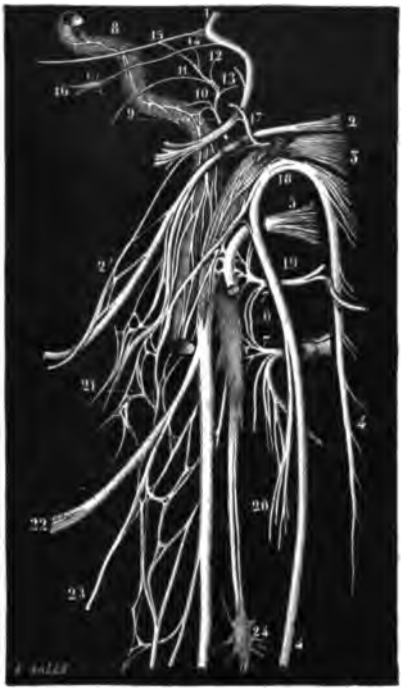

FIG. 84.—DIAGRAM OF THE ROOTS AND COMMUNICATING BRANCHES OF THE VAGUS AND NEIGHBOURING NERVES. (From Sappey, after Hirschfeld and Leveillé.)

1, facial nerve; 2, glossopharyngeal with the petrosal ganglion; 2', connexion of the digastric branch of the facial nerve with the glossopharyngeal nerve; 3, vagus, with its two ganglia; 4, accessory; 5, hypoglossal; 6, superior cervical ganglion of sympathetic; 7, 7, loop of union between the first two cervical nerves; 8, carotid branch of sympathetic; 9, tympanic nerve, given off from the petrosal ganglion; 10, its carotico-tympanic filaments; 11, twig to Eustachian tube; 12, twig to fenestra vestibuli; 13, twig to fenestra cochleæ; 14, small superficial petrosal nerve; 15, large superficial petrosal nerve; 16, otic ganglion; 17, auricular branch of vagus; 18, connexion of accessory with vagus; 19, union of hypoglossal with first cervical nerve; 20, union between the sternomastoid branch of the accessory and that of the second cervical nerve; 21, pharyngeal plexus; 22, superior laryngeal nerve; 23, external laryngeal; 24, middle cervical ganglion of sympathetic.

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[1] The middle constrictor of the pharynx would appear in the monkey to be partly supplied by glossopharyngeal fibres (Beevor and Horsley, *op. cit.* on p. 48).

The *internal laryngeal branch* is continued to the interval between the hyoid bone and the thyroid cartilage, where it perforates the thyrohyoid membrane with the laryngeal branch of the superior thyroid artery, and breaks up into numerous diverging branches which supply the mucous membrane of the greater part of the larynx. Some of these ascend in the ary-epiglottic fold to the base of the tongue and the epiglottis; while others pass downwards to the false vocal cord, and also to the part of the pharyngeal mucous membrane covering the back of the larynx. One long branch descends beneath the ala of the thyroid cartilage, and joins at the lower part of the larynx a similar offset ascending from the recurrent laryngeal nerve.

Varieties.—The *superior laryngeal nerve* may pass on the outer side of the internal carotid artery. The *external laryngeal branch* often arises separately from the main trunk. Offsets of the external laryngeal nerve have been described by different anatomists as passing to the pharyngeal plexus, to the thyroid body, to the sternohyoid, sternothyroid, and thyrohyoid muscles, to the lateral crico-arytenoid muscle, and to the mucous membrane of the true vocal cord and lower part of the larynx. The *internal laryngeal branch* has been seen piercing the thyroid cartilage.[1]

Recurrent laryngeal nerve.—The recurrent or inferior laryngeal nerve of the right side arises at the root of the neck, and turns backwards below the subclavian artery; the nerve of the left side arises in the upper part of the thorax, and is reflected round the arch of the aorta immediately beyond the attachment of the ligamentum arteriosum. Each nerve ascends in the neck behind the common carotid artery, crossing either in front of or behind the inferior thyroid artery, and lying in the groove between the trachea and œsophagus, to the lower border of the cricoid cartilage, where it enters the larynx beneath the inferior constrictor muscle. Under cover of the ala of the thyroid cartilage, the nerve divides into branches which supply all the intrinsic muscles of the larynx, with the exception of the crico-thyroid. It likewise gives a few offsets to the mucous membrane below the rima glottidis, and a connecting filament which joins the long branch of the upper laryngeal nerve beneath the hinder part of the thyroid cartilage: through this communication sensory fibres are probably conveyed to the inferior laryngeal nerve.[2]

The recurrent nerve also furnishes branches to the cardiac plexus, and twigs of communication with the inferior cervical ganglion of the sympathetic, as it turns round the large artery; tracheal and œsophageal branches as it ascends in the neck; and lastly, offsets to the inferior constrictor of the pharynx as it passes beneath that muscle.

Varieties.—In cases of dorsal origin of the right subclavian artery the inferior laryngeal nerve does not turn round that vessel, but passes inwards more directly to the larynx. This nerve has been seen furnishing twigs to the crico-thyroid muscle.

Cardiac branches.—Branches to the heart are given off by the vagus nerve both in the neck and in the thorax.

The *cervical cardiac* branches arise at both the upper and the lower part of the neck. The *upper branches,* one or two, are small, and join the cardiac nerves of the sympathetic. The *lower,* a single branch, arises as the vagus nerve is about to enter the chest. On the right side this branch lies by the side of the innominate artery, and joins one of the cardiac nerves destined for the deep cardiac plexus; it gives some filaments to the coats of the aorta. The branch of the left side crosses the arch of the aorta, and ends in the superficial cardiac plexus.

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[1] A *middle laryngeal nerve* is described by S. Exner as a slender offset from the pharyngeal plexus (in the rabbit and dog directly from the pharyngeal branch of the vagus), which is distributed to the crico-thyroid muscle and to the mucous membrane of the lower part of the larynx by means of twigs which perforate the crico-thyroid membrane (Wiener Sitzungsber. 1884).

[2] Howell and Huber, Journ. of Physiology, xii. 1891.

The *thoracic cardiac* branches of the right side leave the trunk of the vagus as this nerve lies by the side of the trachea, and some are also derived from the first part of the recurrent branch; they pass inwards on the air-tube, and end in the deep cardiac plexus. The corresponding branches of the left side usually come entirely from the recurrent laryngeal nerve.[1]

Pulmonary branches.—Two sets of pulmonary branches are distributed from the vagus nerve to the lung; and they reach the root of the lung, one on its fore-part, the other on its posterior aspect. The *anterior pulmonary nerves*, two or three in number, are of small size. They join with filaments of the sympathetic ramifying on the pulmonary artery, and with these nerves constitute the *anterior pulmonary plexus.* Behind the root of the lung the vagus nerve becomes flattened, and gives several branches of much larger size than the anterior branches, which, with filaments derived from the second, third, and fourth thoracic ganglia of the sympathetic, form the *posterior pulmonary plexus.* Offsets from this plexus extend along the ramifications of the air-tube through the substance of the lung, where they are beset with minute ganglia.

The anterior and posterior pulmonary plexuses of the two sides communicate with one another in an open network across the front and back respectively of the lower end of the trachea, and through these networks fibres are conveyed from both vagus nerves into each lung.

Œsophageal branches.—The œsophagus within the thorax receives branches from the vagus nerves, both above and below the pulmonary branches. The lower branches are the larger, and are derived from the *œsophageal plexus,* which is formed by connecting cords between the nerves of the right and left sides, while they lie in contact with the œsophagus.

Pericardial branches.—Either vagus may furnish a filament to the upper and fore part of the pericardium. Other twigs pass regularly to the back of the pericardium from the œsophageal plexus, and often from the posterior pulmonary plexuses (Zuckerkandl).

Gastric branches.—The branches distributed to the stomach (*gastric nerves*) are terminal branches of both vagus nerves. The nerve of the left side, on arriving in front of the œsophagus, opposite the cardiac orifice of the stomach, divides into many branches: the largest of these extend over the fore-part of the stomach; others lie along its small curvature, and unite with branches of the right nerve and the gastric plexus of the sympathetic; and some filaments are continued between the layers of the small omentum to the hepatic plexus. The right vagus nerve descends on the back of the gullet to the stomach, and distributes branches to the posterior surface of the organ: a large portion of this nerve passes to the cœliac, splenic, and left renal plexuses of the sympathetic.

SUMMARY.—The vagus nerves convey motor fibres to the voluntary muscles of the soft palate (with the exception of the tensor palati), pharynx, and larynx, these last being in part at least derived originally from the accessory; to the

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[1] The *depressor nerve* of the rabbit would appear to be represented in man in many cases by a slender branch which arises from the vagus in common with or just below the superior laryngeal nerve, or perhaps has a double origin, and either descends to the cardiac plexus in conjunction with the superior cardiac nerve of the sympathetic (seldom independently), or rejoins the vagus trunk from 1 to 3 cm. below its origin. In cases where this branch is not to be recognised the fibres are probably contained in the vagus trunk as far as the lower part of the neck. It is thought by Finkelstein and Alpiger that depressor fibres run in the cardiac offset of the external laryngeal nerve. (A. Kriedmann, Arch. f. Anat. 1878; A. Finkelstein, Arch. f. Anat. 1880; A. Viti, Arch. ital. de Biol. v. 1884; G. Békésy, Beiträge zur Anatomie der Herznerven, 1888; M. Alpiger, Langenbeck's Archiv, xl. 1890.)

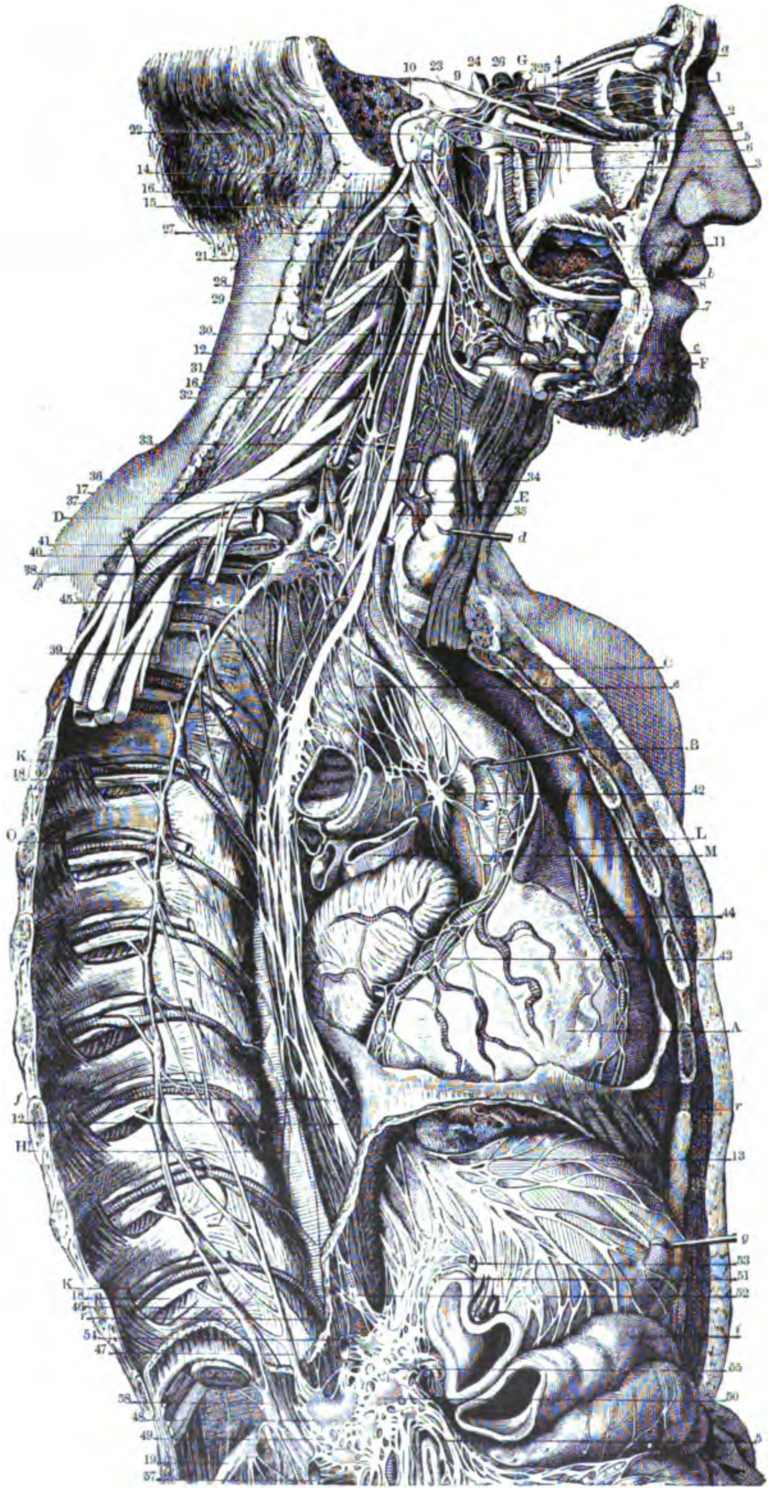
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FIG. 35.

unstriped muscle of the alimentary canal—œsophagus, stomach, and intestine (with the exception of the rectum), and of the air-passages—trachea, bronchi, and their divisions in the lungs. Sensory fibres are furnished to the pharynx, œsophagus, and stomach; to the larynx, trachea, and bronchial ramifications; as well as to the dura mater, the external ear, and the pericardium. The vagi also supply nerves to the heart, both efferent (inhibitory—perhaps received from the accessory) and afferent (depressor); and possibly inhibitory dilator fibres to the vessels of the intestine. Lastly, vagus fibres pass, either directly or through the cœliac plexus and its offsets, to the small intestine, liver, pancreas, spleen, kidneys, and suprarenal bodies. Each vagus nerve is connected with the following cerebral nerves—the accessory, glossopharyngeal, facial, and hypoglossal; also with some spinal nerves; and with the sympathetic in the neck, thorax, and abdomen.

ELEVENTH OR ACCESSORY NERVE.

The **eleventh** or **accessory nerve** is a purely motor nerve, and consists of two parts, *bulbar* and *spinal*, which differ from one another both in their origin and distribution. The bulbar portion arises from the medulla oblongata, and its fibres ultimately join the trunk of the vagus, while the spinal part springs from the spinal cord and is distributed to the sternomastoid and trapezius muscles.

The nerve is formed from the axons of a continuous column of nerve-cells extending from the level of the lower third of the olive to the fifth cervical nerve, in the bulb placed dorso-laterally to the hypoglossal nucleus, and in the spinal cord forming a part of the ventro-lateral group of the ventral horn. From this nucleus the fibres are directed at first dorsally for a short distance, and then turn outwards through the lateral region of the bulb or cord to emerge in a series of filaments from the side of the medulla oblongata below the vagus nerve, and from the lateral column of the spinal cord as low down as the fifth or sixth cervical nerve. The lowest spinal filaments are attached to the middle of the lateral column; the highest ones arise close to and are frequently connected with the dorsal roots of the first and second cervical.

FIG. 35.—VIEW OF THE DISTRIBUTION AND CONNEXIONS OF THE VAGUS AND SYMPATHETIC NERVES ON THE RIGHT SIDE. (Hirschfeld and Leveillé.)

a, lacrymal gland; *b*, sublingual gland; *c*, submaxillary gland and facial artery; *d*, thyroid body; *e*, trachea, below which is the right bronchus cut across; *f*, œsophagus; *g*, stomach, divided near the pylorus; *i*, transverse colon; *r*, the diaphragm.

A, heart; B, aorta, drawn forwards to show the cardiac plexus; C, innominate artery; D, subclavian; E, inferior thyroid; F, a detached part of the external carotid, upon which runs a nervous plexus; G, internal carotid emerging from its canal superiorly; H, descending thoracic aorta; K, intercostal vein; L, pulmonary artery; M, superior vena cava; O, intercostal artery.

1, ciliary nerves; 2, branch of third nerve to inferior oblique muscle; 3, 3, 3, the three divisions of the fifth nerve; 4, ciliary ganglion; 5, sphenopalatine; 6, otic; 7, submaxillary; 8, sublingual; 9, sixth nerve; 10, facial, in its canal, uniting with the sphenopalatine and otic ganglia; 11, glossopharyngeal; 12, right vagus; 13, left vagus spreading on the anterior surface of the stomach; 14, accessory; 15, hypoglossal; 16, 16, nerves of cervical plexus; 17, middle trunk of brachial plexus; 18, intercostal nerve; 19, lumbar nerve; 21, superior cervical ganglion; 22, tympanic nerve; 23, large superficial petrosal nerve; 24, cavernous plexus; 25, sympathetic root of ciliary ganglion; 26, filament to pituitary body; 27, union of sympathetic with upper cervical nerves; 28, vagus nerve; 29, superior laryngeal nerve; 30, pharyngeal plexus; 31, cord of sympathetic; 32, superior cardiac nerve; 33, middle cervical ganglion; 34, twig connecting the ganglion with, 35, the recurrent; 36, middle cardiac nerve; 37, cord of sympathetic; 38, inferior cervical ganglion; 39, the line from this number crosses the nerves proceeding from the brachial plexus; 40, sympathetic twigs surrounding the axillary artery; 41, branch of union with the first intercostal nerve: the line from the letter *e*, pointing to the trachea, crosses the superior, middle, and inferior cardiac nerves; 42, cardiac plexus; 43, 44, right and left coronary plexuses; 45, 46, thoracic portion of the sympathetic cord; 47, great splanchnic nerve; 48, semilunar ganglion; 49, lesser splanchnic; 50, solar plexus; 51, union with the vagus nerve; 52, diaphragmatic plexus; 53, gastric plexus; 54, hepatic; 55, splenic; 56, superior mesenteric; 57, renal plexus; 58, first lumbar sympathetic ganglion.

The development and comparative anatomy of the accessory nerve show that it is really a caudal extension of the vagus and not an independent nerve. In the young human embryo,[1] the spinal portion of the vagus complex possesses motor and sensory roots, but during development the motor fibres gradually predominate, as the sensory fibres and their ganglia tend to disappear. Not unfrequently, however, traces of the ganglia persist in the adult. Various anatomists[2] have directed special attention to the connexion of the dorsal root of the first cervical nerve with the accessory nerve. According to Weigner's observations, there is an anastomosis between the two in about 60 per cent. of cases.

In the bulbar portion of the eleventh nerve fine fibres predominate, although there are some of medium and large size. The spinal portion of the nerve consists almost wholly of large fibres, and fine fibres are absent.

The bulbar portion consists of five or six small bundles which are directed outwards below the vagus and join the spinal part at irregular intervals between the foramen magnum and the foramen jugulare. The spinal part ascends between the ligamentum denticulatum and the posterior roots of the cervical nerves, passes into the skull through the foramen magnum, and is then directed upwards and outwards in the cranial subarachnoid space for about 25 mm. After being joined by the bulbar filaments the common trunk enters the middle compartment of the jugular foramen, where the nerve is contained in the same sheath of dura mater as the vagus, and its bulbar fibres are connected by one or two filaments with the upper ganglion of the vagus. Below the skull the accessory divides into two branches, an internal and an external.

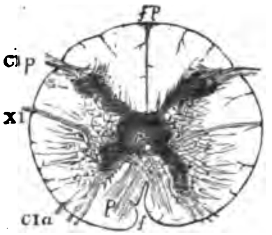

FIG. 36.—SECTION OF UPPER END OF SPINAL CORD, SHOWING ORIGIN OF ACCESSORY NERVE. (After Lockhart Clarke.)

f, ventral, *fp*, dorsal median fissure; *p*, end of decussation of pyramids; CI*a*, CI*p*, ventral and dorsal roots of first cervical nerve; XI, root of accessory nerve; *c*, central canal.

The *internal branch*, which consists of the bulbar fibres, passes over the surface of the lower ganglion of the vagus, and sends its fibres into the pharyngeal and superior laryngeal branches, and into the trunk of that nerve below the ganglion in the manner already described.

The bulbar portion of the accessory nerve is usually considered to provide the motor fibres to the stomach and the inhibitory fibres which pass by the vagus to the heart (A. Waller and others); but according to Van Gehuchten, this portion of the accessory is distributed exclusively to the inferior laryngeal nerve, and to that part of this nerve only which supplies the external thyro-arytenoid muscle. Beevor and Horsley and Réthi state that the motor fibres of the levator palati and azygos uvulæ, as well as, in part at least, those of the constrictor muscles of the pharynx, are also derived from the same source.[3]

The *external branch*, containing the spinal fibres (fig. 37, 5), is directed backwards either across the front of or behind the internal jugular vein, and perforates the sternomastoid muscle, supplying this with branches, and joining among the fleshy fibres with the nerve furnished to the muscle from the cervical plexus. Descending in the next place obliquely across the posterior triangular space of the neck behind the sternomastoid, the nerve passes beneath the trapezius muscle. Here it forms a kind of plexus with branches of the third and fourth cervical nerves, and distributes filaments to the trapezius, which extend nearly to the lower border of the muscle.

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[1] G. L. Streeter, American Journal of Anatomy, iv. No. 1.

[2] M. Holl, Arch. f. Anat. 1878; J. Kazzander, Arch. f. Anat. 1891; and K. Weigner, Anat. Hefte, xvii. 1901.

[3] Beevor and Horsley, Proc. Roy. Soc. 1888; W. A. Turner, Journ. Anat. and Phys. xxiii.; L. Réthi, Wiener Sitzungsber. 1892 and 1893; M. Grossmann, Wiener Sitzungsber. 1889; Grabower, Centralbl. f. Physiol. iii. 1890; E. v. Navratil, Ungar. Arch. f. Med. ii. 1894; Van Gehuchten, Système Nerveux, 1906.

Varieties.—The lower limit of the origin of the spinal part of the nerve was found by Holl to range from the third to the seventh cervical nerve, but in the greater number of cases it corresponded to the fifth or sixth nerve. It was seen by Sœmmering opposite the first thoracic nerve. The spinal part of the nerve in one case pierced the dura mater below the first cervical nerve, and re-entered the spinal theca higher up (Holl). The external portion of the accessory nerve sometimes passes beneath the sternomastoid without piercing the muscle. In one instance this nerve has been seen terminating in the sternomastoid muscle, the trapezius being supplied entirely by the third and fourth cervical nerves (Curnow). In rare cases it has been observed sending a branch to join the descending cervical nerve.

SUMMARY.—The accessory nerve supplies the sternomastoid and trapezius muscles by its external or spinal branch. The levator palati and azygos uvulæ, the constrictors of the pharynx, and possibly the adductors of the vocal cord, are supplied by its internal or bulbar branch, and the inhibitory fibres of the heart may be derived from the same source. It communicates with the dorsal roots of the first and second cervical nerves in the spinal canal, the vagus below the base of the skull, and the branches from the cervical plexus to the sternomastoid and trapezius muscles in the neck.

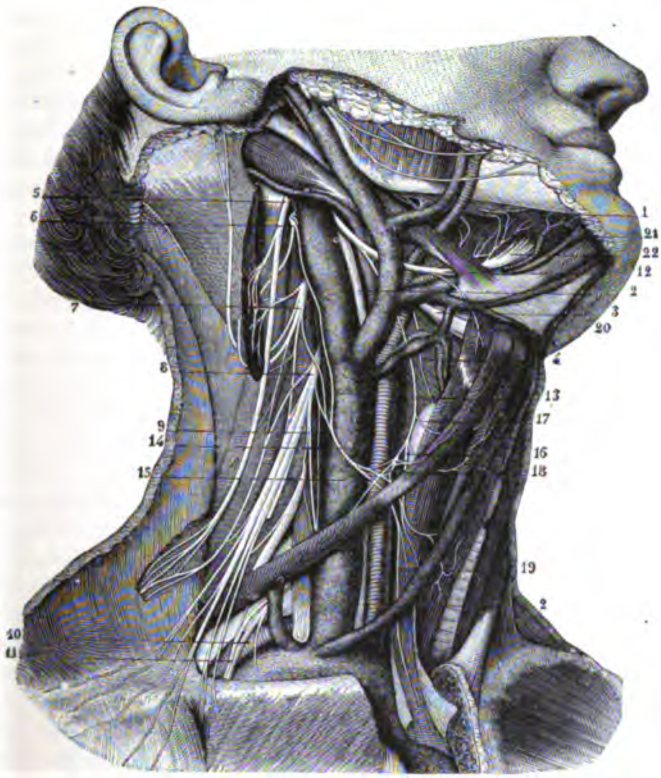

FIG. 87.—VIEW OF THE DISTRIBUTION OF THE ACCESSORY AND HYPOGLOSSAL NERVES. (From Sappey, after Hirschfeld and Leveillé.) ½.

1, lingual nerve; 2, vagus nerve; 3, superior laryngeal (represented too large); 4, external laryngeal branch; 5, accessory nerve; 6, second cervical; 7, third; 8, fourth; 9, origin of phrenic nerve; 10, nerve to subclavius; 11, external anterior thoracic nerve; 12, hypoglossal nerve; 13, descending cervical nerve; 14, communicating cervical nerve; 15, 16, 18, 19, branches from the plexiform union of these nerves to the sternohyoid, sternothyroid and omohyoid muscles; 17, branch to the anterior belly of the omohyoid muscle; 20, branch to the thyrohyoid muscle; 21, communicating twigs from the hypoglossal to the lingual nerve; 22, terminal branches of the hypoglossal nerve.

TWELFTH OR HYPOGLOSSAL NERVE.

The **twelfth** or **hypoglossal nerve** is a purely motor nerve which arises from a nucleus placed ventro-laterally to the central canal in the lower part of the medulla oblongata, and extending upwards beneath the trigonum hypoglossi of the fourth ventricle. Thence the fibres pass obliquely forwards and outwards, between the anterior and lateral areas of the bulb, and form a series of from ten to fifteen fine roots which emerge along the groove separating the pyramid from the olivary body. The filaments are directed outwards behind the vertebral artery, and are usually collected into two bundles which perforate the dura mater separately opposite the anterior condylar foramen, and are united into a single trunk as they pass through that opening.

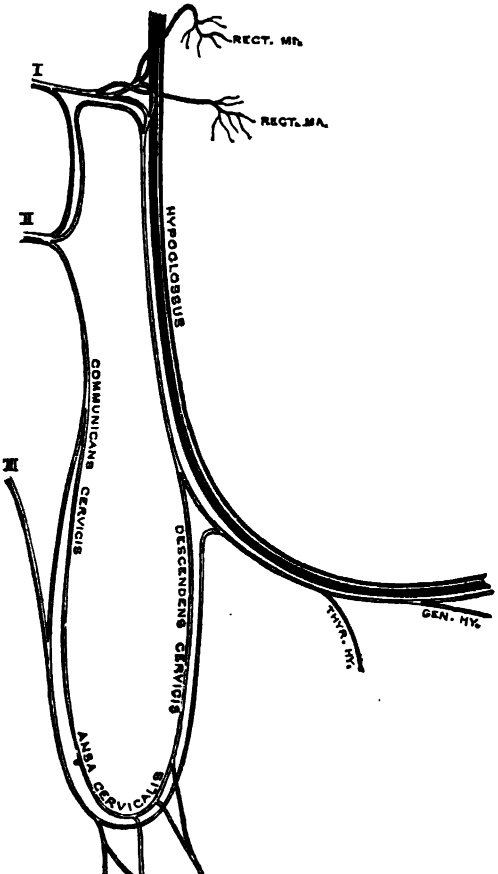

FIG. 38.—PLAN OF THE CONNEXIONS OF THE HYPOGLOSSAL WITH THE CERVICAL NERVES, AND THE FORMATION OF THE ANSA CERVICALIS. (After Holl.)

As it leaves the anterior condylar foramen the nerve is very deeply placed on the inner side of the deep cervical vessels and the vagus nerve. Winding round the lower ganglion of the vagus, to which it is closely bound by connective tissue, the hypoglossal nerve descends, inclining at the same time gradually forwards between the internal carotid artery and jugular vein, to the lower border of the digastric muscle. At this level it curves forwards round the commencement of the occipital artery, the sternomastoid branch of which turns downwards over the nerve, and is thence directed forwards above the hyoid bone to the under part of the tongue. In the latter part of its course it passes beneath the tendon of the digastric, the lower end of the stylohyoid, and the mylohyoid muscles; it crosses the external carotid and the lingual arteries; and it rests upon the hyoglossus muscle, being accompanied by the ranine vein of the tongue. At the anterior border of the hyoglossus it is connected with the lingual branch of the fifth nerve, and then penetrates the fibres of the genioglossus muscle, dividing into branches which are distributed to the muscular substance of the tongue.

While passing through the anterior condylar foramen, the hypoglossal nerve gives off one or two minute *recurrent* twigs which ramify in the dura mater around the foramen magnum, and in the diploë of the occipital bone. They were thought by Luschka to be formed by recurrent fibres derived from the lingual nerve, but it is possible that they consist of fibres which ascend from the communication with the first cervical nerve, or from the sympathetic (Rüdinger). The branches arising from the nerve in the neck are partly filaments of communication with other nerves, but mainly offsets of distribution to muscles connected with the hyoid bone and larynx, and to the muscles of the tongue.

Branches of communication.—Close below the skull the hypoglossal nerve is united by a filament with the superior cervical ganglion of the sympathetic, by one or more twigs with the loop between the first and second cervical nerves, and with the ganglion of the trunk of the vagus by fibres which pass between the two nerves where they are in close connexion with one another.

As the nerve turns round the occipital artery, it is joined by the small lingual branch of the vagus (p. 43); and in the submaxillary region, it is connected with the lingual branch of the fifth nerve by one or two slender loops over the fore-part of the hyoglossus muscle.

Branches of distribution.—One or two slender twigs leave the hypoglossal nerve close below the skull, and pass to the mesial aspect of the internal jugular vein, where they are often joined by filaments from the superior cervical ganglion of the sympathetic (Luschka).

The *descending cervical nerve* (*ramus descendens hypoglossi*) consists mainly of fibres which pass to the hypoglossal from the first and second cervical nerves in the communication below the skull. Leaving the trunk as it turns round the occipital artery, or a little higher up, the descending nerve runs downwards on the surface of the common carotid artery, inclining gradually from the outer to the inner side, and being placed generally within, but sometimes on the front of, the carotid sheath. After having given off a branch to the anterior belly of the omohyoid muscle, it joins about the middle of the neck in a loop (*ansa cervicalis*) with the *communicating cervical branches* from the second and third cervical nerves. The concavity of the loop is turned upwards, and the connexion between the nerves is frequently effected by two or more interlacing filaments which form a small plexus. From this interlacement of the nerves offsets are continued backwards to the posterior belly of the omohyoid, and downwards to the sternohyoid and sternothyroid muscles. The branch to the thyrohyoid muscle is a separate twig also composed of fibres proceeding from the cervical nerves, and leaving the hypoglossal trunk as it approaches the hyoid bone.

As it lies beneath the mylohyoid, the nerve gives offsets to the styloglossus, hyoglossus, and geniohyoid muscles, and the terminal branches, penetrating the genioglossus, supply that muscle and the intrinsic muscles of the tongue. According to Holl, the nerve to the geniohyoid is of cervical origin.

The fibres proceeding from the first and second cervical nerves do not become mingled with those of the hypoglossal trunk, but for the most part form a small cord which can be separated from the latter by removing the common sheath, and followed down into the descending cervical nerve. A minute funiculus runs proximally with the hypoglossal nerve, and others pass on the deep aspect of the trunk to the recti antici. The descending cervical nerve also contains fibres which pass upwards from the communicating branches and run peripherally to enter the nerves of the thyrohyoid and geniohyoid muscles.[1]

The spinal origin of the nerves of the infrahyoid muscles has also been demonstrated experimentally in the monkey by Beevor and Horsley,[2] who found that stimulation of the hypoglossal roots within the skull produced no effect on these muscles, while they were called into action by stimulating the first and second cervical nerves. The sternohyoid and sternothyroid were supplied mainly from the first nerve, and the omohyoid from the second.

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[1] See M. Holl, 'Beobachtungen über die Anastomosen des Nervus hypoglossus,' Zeitschr. f. Anat. u. Entw. 1876.

[2] *Op. cit.* on p. 48.

The fibres of the hypoglossal nerve are of medium size, resembling in this respect those of the facial nerve, and being smaller than those of most of the motor nerves passing to voluntary muscles (Gaskell).

Varieties.—In one instance, recorded by Rüdinger, the hypoglossal nerve was found taking its superficial origin from the posterior surface of the medulla oblongata. The vertebral artery is not unfrequently found passing forwards between, very rarely above, the roots of the nerve. The right and left nerves are occasionally united by a cross branch or loop in the substance of the geniohyoid, or between that and the genioglossus muscle. In rare cases, the twelfth nerve gives filaments to the mylohyoid, to the digastric, or to the stylohyoid muscle.

The descending cervical nerve sometimes appears to be derived either altogether from the vagus or from both the vagus and hypoglossal nerves, but it can always be shown by dissection that these varieties of origin are only apparent, resulting from the temporary adhesion of the filaments of this branch to those of the vagus. A filament is occasionally continued from the descending cervical nerve into the thorax, where it joins the phrenic or the cardiac nerves; in the latter case it is probably composed of fibres from the vagus or the sympathetic, which have joined the hypoglossal or the descending nerve. This nerve has also been seen sending a branch to the sternomastoid muscle.

In some animals the twelfth nerve possesses a dorsal root furnished with a ganglion, like a spinal nerve. A similar condition has been met with in a few instances in man.

SUMMARY.—The hypoglossal nerve proper supplies all the muscles of the tongue, both intrinsic and extrinsic. Fibres derived from the first three cervical nerves, which are associated with the hypoglossal for a part of their course, are distributed to the infrahyoid muscles and the geniohyoid. Others of uncertain origin pass to the skull and dura mater, and to the internal jugular vein. The hypoglossal forms connexions with the vagus, lingual, upper three cervical nerves, and with the sympathetic.

SPINAL NERVES.

The spinal nerves are characterised by their origin from the spinal cord, and their transmission outwards from the spinal canal in the intervals between the vertebræ. There are, in all, thirty-one pairs of these nerves, and, according to the region in which they issue from the spinal canal, they are named cervical, thoracic, lumbar, sacral, and coccygeal.

By universal usage each pair of nerves in the thoracic, lumbar, and sacral regions is named in correspondence with the vertebra below which it emerges. Of the eight pairs of nerves between the cranium and the first thoracic nerve, the uppermost is placed above the atlas, and the second and following nerves below the seven cervical vertebræ in succession. These eight pairs are usually reckoned as eight cervical nerves, but the first is also distinguished by the name of suboccipital nerve. The nerves of the thirty-first pair emerge from the lower end of the sacral canal, pass below the first vertebra of the coccyx, and are named coccygeal.

Varieties.—The spinal nerves vary in number with any deviation from the usual number of the segments of the vertebral column. Sometimes an additional coccygeal nerve exists. Among seven cases which were examined by Schlemm two coccygeal nerves were found on each side in one instance, and on one side in another case. According to Rauber, vestiges of these, and also of a third pair of coccygeal nerves, are normally present in the bundles of medullated fibres contained in the filum terminale. On the other hand, the coccygeal nerve often appears to be wanting, being united to the filum terminale (Rauber, Kadyi).

THE ROOTS OF THE SPINAL NERVES.

Each spinal nerve springs from the spinal cord by two roots which approach one another as they quit the spinal canal, and join in the corresponding intervertebral foramen into a single cord; and each cord so formed separates immediately into two divisions, one of which is destined for parts in front of the spine, the other for parts behind it.

General arrangement.—The roots of the nerves arise on each side of the spinal cord by two nearly continuous series of filaments (*fila radicularia*), the ventral (anterior) of which emerge from the ventro-lateral column opposite the ventral (anterior) cornu of the grey matter, while the dorsal (posterior) are attached in a narrower line along the dorso-lateral sulcus of the cord. The filaments composing a single nerve-root vary in number from five to ten, and converge from above downwards as they pass from the cord to the dura mater, where each root enters a special aperture.

The *dorsal roots* of the nerves are distinguished from the ventral roots by their greater size, which is due to their constituent filaments being both more numerous and individually larger than those of the ventral roots. Each dorsal root is further marked by a ganglion (*spinal* or *intervertebral*), of a size proportionate to that of the nerve on which it is formed. The cells of these ganglia are unipolar, the single process of each cell subsequently dividing into two branches, so that the ganglia give origin to the afferent fibres of the spinal nerves, both central and peripheral.

The ganglia are in general placed in the intervertebral foramina, immediately beyond the spots at which the roots perforate the dura mater lining the spinal canal. The first and

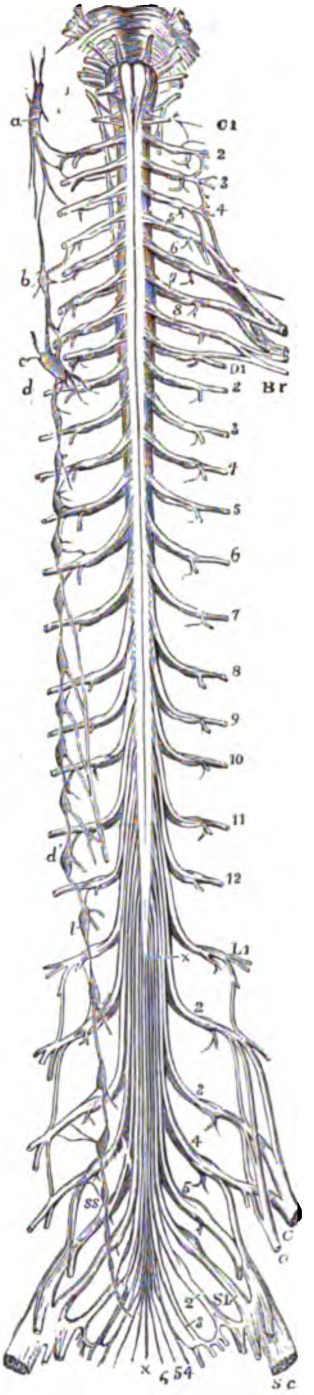

Fig. 39.—Diagrammatic outline of the roots and first part of the spinal nerves, together with the sympathetic trunk of one side. (Allen Thomson.) ½.

The view is taken from the ventral aspect. In the upper part of the figure the pons and medulla oblongata are represented, and the roots of the several cerebral nerves from the trigeminal to the hypoglossal are indicated. On the left side C 1 is placed opposite the first cervical nerve; and the numbers 2 to 8, following below, indicate the corresponding cervical nerves; Br, brachial plexus; D 1 is placed opposite the intercostal part of the first thoracic (dorsal) nerve, and the numbers 2 to 12, following, mark the corresponding thoracic nerves; L 1, the first lumbar nerve, and the numbers 2 to 5, following, the remaining lumbar nerves; C, the femoral, and *o*, the obturator nerve; S 1, the first sacral, and the following numbers 2 to 5, the remaining sacral nerves; 6, the coccygeal nerve; Sc, sciatic nerve; × ×, the filum terminale of the cord.

On the left side of the figure the following letters indicate parts of the sympathetic nerve—viz. *a*, the superior cervical ganglion communicating with the upper cervical spinal nerves and continued below into the sympathetic cord; *b*, the middle cervical ganglion; *c*, *d*, the lower cervical ganglion united with the first thoracic; *d'*, the eleventh thoracic ganglion; from the sixth to the ninth thoracic ganglion the origins of the great splanchnic nerve are shown; *l*, the highest lumbar ganglion; *s s*, the upper sacral ganglion. In the whole extent of the sympathetic cord, the twigs of union with the spinal nerves are shown.

second cervical nerves, however, which do not pass through intervertebral foramina, have their ganglia in the corresponding position as they lie over the neural arches of the vertebræ. The ganglia of the sacral nerves are contained in the spinal canal, that of the last nerve being occasionally at some distance from the point at which the nerve issues. The ganglion of the coccygeal nerve is placed in the canal within the sac of the dura mater, and at a variable distance from the origin of the nerve.

The filaments of the dorsal root of the nerve are collected into two bundles as they approach the ganglion, and the inner extremity of the oval-shaped ganglion is usually bilobate, the lobes corresponding to the two bundles of filaments.

The *ventral roots* of the spinal nerves are smaller than the dorsal, and are devoid of ganglia, their fibres arising from the cells of the grey matter of the spinal cord, and mainly from those of the ventral cornu. Their filaments also tend to be collected into two bundles near the intervertebral foramen.[1]

Both ventral and dorsal roots of all the spinal nerves contain fibres of very various sizes—large, medium (10 μ to 5 μ), and fine—but the proportion in which the different groups occur is not the same throughout. The ventral roots of the cervical, lumbar, and sacral nerves consist mainly of large and medium-sized fibres, fine fibres being present only in small number, generally not exceeding one-sixth of the whole. Those of the thoracic nerves, however, as well as the coccygeal, show a preponderance of fine fibres, which are about three times as numerous as the larger ones. The finest fibres (2·6 μ and less) are abundant in the ventral roots of the thoracic nerves, but rare in the other regions, except in the last two sacral and the coccygeal nerves. In the dorsal roots the small fibres are about equal in number to the medium-sized and large fibres together; and fibres of the largest size (above 20 μ), which are frequent in the ventral roots, are here scanty.

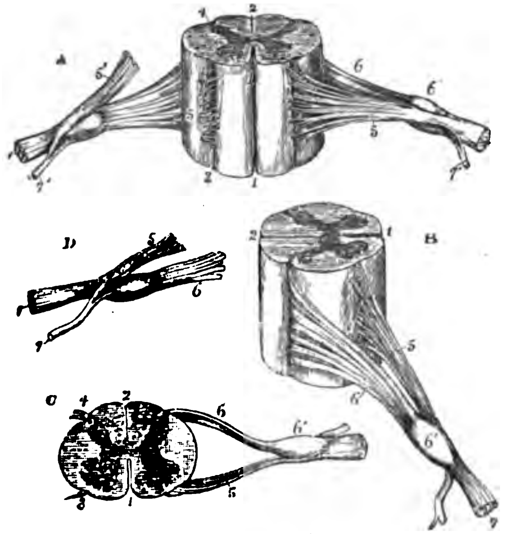

FIG. 40.—DIFFERENT VIEWS OF A PORTION OF THE SPINAL CORD FROM THE CERVICAL REGION, WITH THE ROOTS OF THE NERVES. Slightly enlarged. (Allen Thomson.)

In A, the ventral surface of the specimen is shown, the ventral nerve-root of the right side being divided; in B, a view of the right side is given; in C, the upper surface is shown; in D, the nerve roots and ganglion are shown from below. 1, ventral median fissure; 2, dorsal median furrow and septum; 3, origin of the ventral nerve-roots; 4, dorso-lateral groove, into which the filaments of the dorsal root are seen to sink; 5, ventral root passing over the ganglion; 5', in A, the ventral root divided; 6, dorsal root, the fibres of which enter 6', the ganglion; 7, the ventral, and 7', the dorsal branch of the nerve, each of which is seen in A and D to be derived in part from the ventral and in part from the dorsal root.

Varieties.—The dorsal root of the first cervical nerve is sometimes wanting (8 per cent., Kazzander); or it may arise partly or wholly from, or in common with, the accessory nerve (see p. 47). A defect in the roots of the thoracic nerves is said to be very common by Adamkiewicz, who found in sixteen spinal cords only three with the full number of thoracic roots; in three there was absence of both ventral and dorsal roots of one nerve, in three absence of a dorsal root only, and in seven absence of one ventral root.[1] Communications between the root-filaments (especially the dorsal) of adjoining nerves are frequently met with. Small detached portions of the spinal ganglia (*ganglia aberrantia* of Hyrtl) are sometimes found on the dorsal roots of the upper cervical nerves. The ganglia of the lumbar and upper sacral nerves are often double, there being a distinct swelling on each of the bundles of the dorsal root. The ganglion of the suboccipital nerve may be situated within the dural sheath, or be wanting (9 per cent., Kazzander), but in such cases there are probably nerve-cells interspersed in the dorsal root. According to Rattone, there are regularly scattered nerve-cells along the dorsal roots of all the spinal nerves.[2] In the cat there are scattered ganglion-cells among the fibres of many of the ventral roots.[3]

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[1] The origin of the nerve-fibres of the spinal nerves is dealt with under the Spinal Cord (see Part I.).

Size.—The roots of the upper *cervical nerves* are smaller than those of the lower nerves, the first being much the smallest, and the sixth the largest. The dorsal roots of these nerves, with the exception of the first in which the ventral root is larger than the dorsal, exceed the ventral in size more than in the other spinal nerves, and they are likewise composed of filaments which are considerably larger than those of the ventral roots.

The roots of the *thoracic nerves*—exception being made of the first, which resembles the lowest cervical nerves and is associated with them in a part of its distribution—are of small size, and vary but slightly, or not at all, from the second to the last. The filaments of both roots are thinly strewed over the spinal cord, and are slender, those of the dorsal exceeding in thickness those of the ventral root in only a small degree.

The roots of the lower *lumbar*, and of the upper *sacral nerves*, are the largest of all the spinal nerves; those of the lowest sacral and of the coccygeal nerve are, on the other hand, the smallest. All these nerves are crowded together upon the lower end of the cord. Of these nerves the ventral roots are the smaller, but the disproportion between the ventral and dorsal roots is not so great as in the cervical nerves.

Length.—The place at which the roots of the upper cervical nerves are connected with the spinal cord being nearly opposite the foramina by which they respectively leave the canal, these roots are comparatively short. But the distance between the two points referred to is gradually augmented from nerve to nerve downwards, so that the place of origin of the lower cervical nerves is the depth of at least one vertebra, and that of the lower thoracic nerves about the depth of three vertebræ, above the foramina by which they respectively emerge from the canal. Moreover, as the spinal cord extends no farther than the first lumbar vertebra, the length of the roots of the lumbar, sacral, and coccygeal nerves increases rapidly from nerve to nerve, and in each case may be estimated by the distance of the foramen of exit from the extremity of the cord. Owing to their length, and the appearance they present in connexion with the spinal cord, the aggregation of the roots of the nerves last referred to has been named the *cauda equina*.

The cervical and thoracic nerve-roots pierce the dura mater opposite the intervertebral foramina through which they leave the spinal canal, and the extra-dural length of nearly all these nerve-roots is about 1 cm.; but in the lumbar and sacral regions the nerve-roots pierce the dura mater higher up than their corresponding intervertebral foramina, the distance between the two points increasing from above downwards. This is associated with an increasing obliquity and length of the extra-dural course of the nerve-roots, which becomes specially marked in the lower sacral region, the extra-dural length of the roots of the third sacral being about 3·5 cm. and that of the last sacral about 6 cm.

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[1] Virchow's Archiv, lxxxviii. 1882.

[2] Internat. Monatschr. f. Anat. u. Hist. i. 1884.

[3] Schäfer, Proc. Roy. Soc. xxxi. 1881.

A diagram showing the level at which the several roots arise from the cord in relation to the spines of the vertebræ, as determined by R. W. Reid, is given on page 61 of Part I. of Neurology.

The average vertical length of the spinal nerve-roots in eight adult subjects is shown in the following table by Soulié:[1]

NERVE.	AVERAGE LENGTH.	NERVE.	AVERAGE LENGTH.
1st cervical . .	3 mm.	9th thoracic .	52 mm.
2nd " . .	8 "	10th " .	55 "
3rd " . .	16 "	11th " .	58 "
4th " . .	18 "	12th " .	81 "
5th " . .	20 "	1st lumbar .	91 "
6th " . .	23 "	2nd " .	110 "
7th " . .	25 "	3rd " .	132 "
8th " . .	27 "	4th " .	151 "
1st thoracic . .	29 "	5th " .	170 "
2nd " . .	33 "	1st sacral . .	185 "
3rd " . .	38 "	2nd " . .	196 "
4th " . .	43 "	3rd " . .	221 "
5th " . .	45 "	4th " . .	239 "
6th " . .	47 "	5th " . .	262 "
7th " . .	49 "	Coccygeal . .	266 "
8th " . .	49 "		

Direction.—The first cervical nerve is directed horizontally outwards. The roots of the lower cervical and thoracic nerves at first descend over the spinal cord, held in contact with it by the arachnoid, till they arrive opposite the several intervertebral foramina, where they are directed horizontally outwards. The nerves of the cauda equina run in the direction of the spinal canal.

Division of the nerves.—The two roots of each of the spinal nerves unite immediately beyond the ganglion, and the trunk thus formed separates, as already mentioned, into two divisions, a ventral (anterior) and a dorsal (posterior), which are called primary branches or divisions, and each of which contains fibres proceeding from both the ventral and dorsal roots.

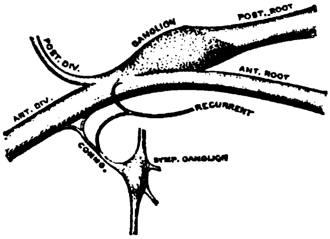

FIG. 41.—PLAN OF THE MODE OF BRANCHING OF A SPINAL NERVE.

Before dividing in the manner above described each spinal nerve gives off a small *recurrent* or *meningeal branch*, which is joined by a filament from the communicating cord between the ventral division of the nerve and the sympathetic, and then runs inwards through the intervertebral foramen to the spinal canal, where it is distributed to the vertebræ and ligaments, to the blood-vessels of the canal, and to the dura mater (Luschka, Rüdinger).

DORSAL (POSTERIOR) BRANCHES OF THE SPINAL NERVES.

The dorsal branches (*rami posteriores*) of the spinal nerves are, with few exceptions, smaller than those given to the fore-part of the body. Springing from the trunk which results from the union of the roots of the nerve in the intervertebral foramen, or frequently by separate fasciculi from the two roots, each turns backwards at once, and soon divides into two parts, distinguished as lateral (*external*) and mesial (*internal*), distributed to the muscles and the integument behind the spine. The first cervical, the fourth and fifth sacral, and the coccygeal are the only nerves the dorsal branches of which do not separate into lateral and mesial branches.

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[1] See Poirier's Traité d'Anatomie, tome iii. fasc. 3, p. 938.

DORSAL DIVISIONS OF CERVICAL NERVES.

Suboccipital nerve.—The dorsal branch of the first cervical or suboccipital nerve, slightly larger than the ventral, emerges over the posterior arch of the atlas, between this and the vertebral artery, and enters the space bounded by the larger rectus and the two oblique muscles, where it divides into branches for the surrounding muscles.

One branch descends to the inferior oblique, and gives a filament, through or over the fibres of that muscle, to join the second cervical nerve.

Another ascends over the rectus posticus major muscle, supplying it and the smaller rectus.

A third enters the superior oblique muscle.

A fourth passes backwards into the complexus, where that muscle covers the nerve and its branches.

Variety.—A *cutaneous branch* is occasionally given to the back of the head: it accompanies the occipital artery, and is connected beneath the integument with the great and small occipital nerves.

The remaining cervical nerves.—The *lateral branches* give only muscular offsets, and are distributed to the splenius and the slender muscles prolonged to the neck from the erector spinæ—viz. the cervicalis ascendens, and the transversalis cervicis with the trachelo-mastoid. That of the second nerve is the largest of the series of lateral branches of the cervical nerves, and is often united to the corresponding branch of the third.

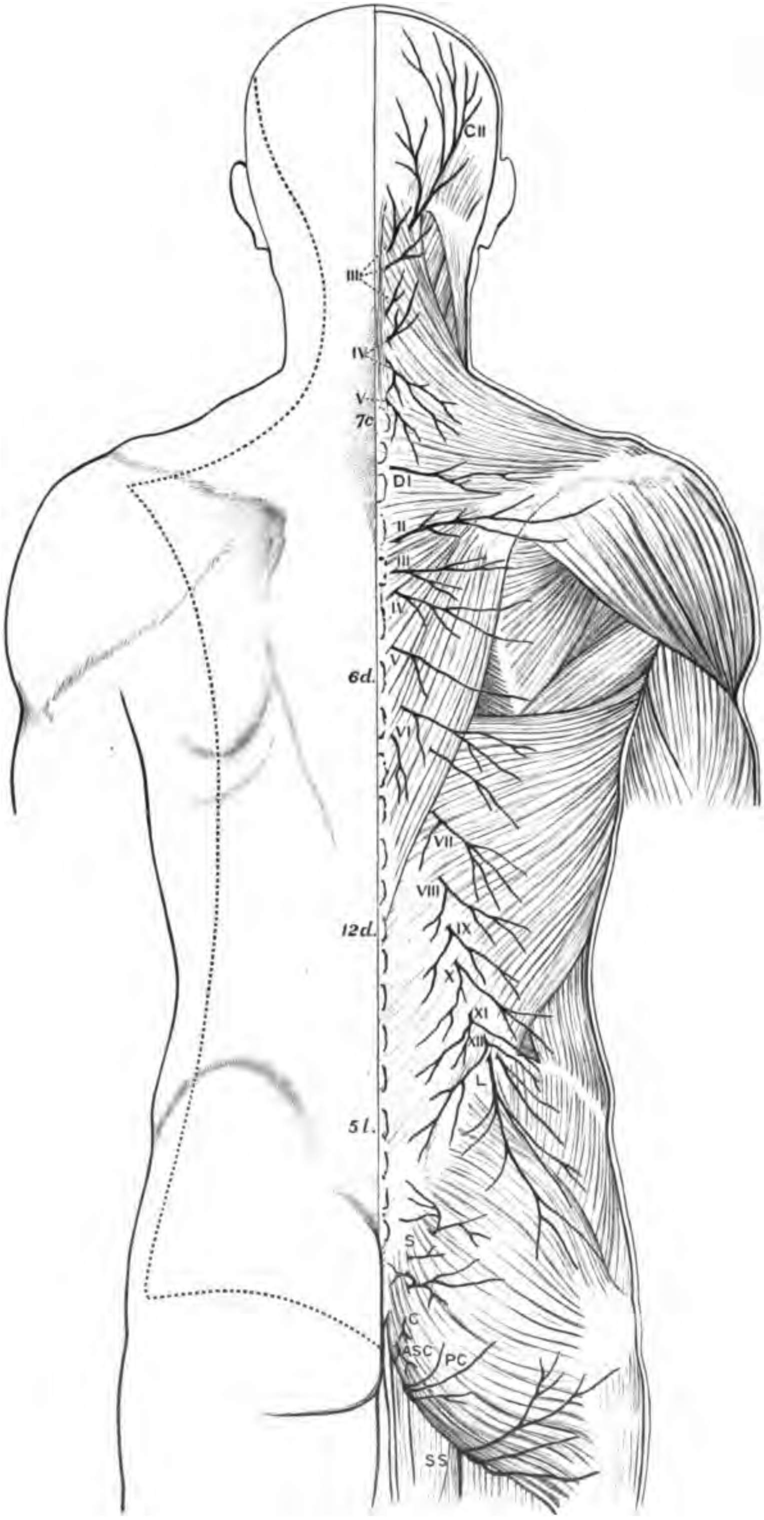
The *mesial branches*, larger than the external, are differently disposed at the upper and the lower parts of the neck. That of the second cervical nerve is named, from its size and destination, the *great occipital*, and will receive separate notice. The rest are directed inwards to the spinous processes of the vertebræ. Those derived from the third, fourth, and fifth nerves pass over the semispinalis and beneath the complexus, giving offsets to those muscles and to the multifidus, and, having reached the spines of the vertebræ, pierce the splenius and trapezius, to be distributed in the integument over the latter muscle. From the cutaneous branch of the third nerve an offset passes upwards to the integument on the lower part of the occiput, lying at the inner side of the great occipital nerve; this is sometimes called the *third occipital nerve*.

Between the inner branches of the first three or four cervical nerves, beneath the complexus, there are frequently communicating loops; this communication has been designated by Cruveilhier the *posterior cervical plexus*.

The mesial branches from the lowest three cervical nerves are placed beneath the semispinalis muscle, and end in the muscular structure, without furnishing any offset to the skin. These three nerves are the smallest of the series.

The **great occipital nerve** is directed upwards across the inferior oblique muscle, and is transmitted to the surface through the complexus and trapezius muscles, giving twigs to the complexus. It then passes upwards and outwards covered by a layer of thick dense fascia, and, joining the occipital artery, divides into branches which radiate over the back of the head, the most external communicating with the small occipital nerve.

Varieties.—The great occipital nerve occasionally sends a branch to the auricle, or replaces, to a greater or less extent, the small occipital nerve (p. 63). The lateral division of the second nerve is said sometimes to give off a cutaneous branch or a twig to the superior oblique. Either


CII
III
IV
V
7c
DI
II
III
IV
V
6d.
VI
VII
VIII
12d.
IX
X
XI
XII
L
5l.
S
C
ASC
PC
SS

the sixth or the eighth cervical nerve may furnish a cutaneous branch: not infrequently that from the eighth is of considerable size (H. M. Johnston). On the other hand, the cutaneous branch of the fifth is sometimes wanting.

DORSAL DIVISIONS OF THORACIC NERVES.

The *lateral branches* increase in size from above downwards. They are directed through or beneath the longissimus dorsi to the space between that muscle and the ilio-costalis or accessorius, and supply the several divisions of the erector spinæ. The lower five or six nerves give cutaneous twigs, which are transmitted to the integument in a line with the angles of the ribs.

The *mesial branches* of the upper six or seven thoracic nerves pass backwards in the interval between the multifidus spinæ and the semispinalis muscle; they supply the transverso-spinales muscles, and become cutaneous by the side of the spinous processes of the vertebræ. The cutaneous branch of the second nerve, and sometimes of others, extends outwards over the scapula. The mesial branches of the lower thoracic nerves are placed between the multifidus spinæ and longissimus dorsi, and end in the multifidus without giving branches to the integument. Where cutaneous nerves are supplied by the mesial branches, there are generally none from the lateral branches of the same nerves, and *vice versâ*.

The cutaneous offsets of the thoracic nerves run obliquely downwards in their passage between and through the muscles, so that they become superficial and are distributed to the skin at a level below that of the vertebræ to which they correspond (see fig. 42). This descent is but slight in the case of the upper branches, which are derived from the mesial divisions of the nerves, and which in their subcutaneous course are directed nearly horizontally outwards, but it becomes progressively greater in the lower branches, proceeding from the lateral divisions, and the offset of the twelfth thoracic only makes its appearance a little distance above the iliac crest. There is considerable variety in the size and in the extent of distribution of the several nerves, which often differ on the two sides of the body. The sixth thoracic nerve may supply the skin opposite the spinous process of the twelfth thoracic vertebra, and twigs from one or two of the lowest thoracic nerves frequently pass over the iliac crest to the skin of the buttock.[1]

Varieties.—The cutaneous offset of the first thoracic nerve is sometimes absent. There are not infrequently cutaneous branches from both divisions of the middle (sixth, seventh, and eighth) thoracic nerves.

DORSAL DIVISIONS OF LUMBAR NERVES.

The *lateral branches* enter the erector spinæ, and give branches to that muscle. From the upper three cutaneous nerves are supplied; and from the last, a filament descends to the corresponding branch of the first sacral nerve. The *cutaneous nerves* given from the lateral branches of the first three lumbar nerves (*nervi clunium superiores*) pierce the fleshy part of the ilio-costalis and the aponeurosis of the latissimus dorsi; they cross the iliac crest near the edge of the erector spinæ, and terminate in the integument of the gluteal region.

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[1] See Wardrop Griffith and Oliver, 'On the Distribution of the Cutaneous Nerves of the Trunk,' Proc. Anatom. Soc. 1890, in Journ. Anat. xxiv.

FIG. 42.—CUTANEOUS DISTRIBUTION OF THE DORSAL BRANCHES OF THE SPINAL NERVES. (G. D. Thane.)

On the right side the nerves are shown lying on the superficial muscles; on the left side the limit of the skin-area supplied by these nerves is indicated by the dotted line. 7 *c.*, seventh cervical spine; 6 *d.*, sixth thoracic; 12 *d.*, twelfth thoracic; 5 *l.*, fifth lumbar.

The nerves are indicated as follows: C II, great occipital, from second cervical; III to V, third to fifth cervical; D I, first thoracic; II to XII, second to twelfth thoracic; three cutaneous branches are given by the sixth thoracic, two from the internal, and one from the external division; L, lumbar; S, upper sacral; C, lower sacral and coccygeal; ASC, ventral divisions of the last sacral and coccygeal; PC, perforating cutaneous; SS, posterior cutaneous of the thigh.

One or more of the filaments may be traced as far as the great trochanter of the femur.

The *mesial branches* wind backwards in grooves close below the mamillary processes of the vertebræ, and sink into the multifidus spinæ muscle.

DORSAL DIVISIONS OF SACRAL NERVES.

The dorsal divisions of these nerves, except the last, issue from the sacrum through its posterior foramina. The first three are covered at their exit from the bone by the multifidus spinæ muscle, and bifurcate like the dorsal trunks of the other spinal nerves; but the remaining two, which continue below that muscle, are not thus divided.

The *mesial branches of the first three sacral nerves* are small, and are lost in the multifidus spinæ muscle.

The *lateral branches* of the same nerves are united with one another, and with the last lumbar and fourth sacral nerves, so as to form a series of anastomotic loops on the upper part of the sacrum. From these, branches are then directed outwards to the cutaneous or posterior surface of the great sacrosciatic ligament, where, covered by the gluteus maximus muscle, they form a second series of loops, and end as cutaneous nerves (*nervi clunium medii*). The latter pierce the great gluteus muscle in a line drawn from the posterior superior iliac spine to the tip of the coccyx. They are commonly two in number—one is near the lower part of the sacrum, the other by the side of the coccyx. All are directed outwards over the great gluteal muscle.

In six dissections by Ellis the above arrangement was found to be the most frequent. The variations to which it is liable are these: the first nerve may not take part in the formation of the second series of loops, and the fourth may be associated with them. From the first three sacral nerves filaments are given to the sacro-iliac articulation (Luschka, Rüdinger). Small cutaneous twigs from the mesial branches of the lower lumbar and upper sacral nerves are described by many anatomists.

The *dorsal divisions of the last two sacral nerves* are smaller than those above them, and are not divided into lateral and mesial branches. They are connected with each other by a loop on the back of the sacrum, and the lowest is joined in a similar manner with the coccygeal nerve; one or two filaments from these sacral nerves are distributed in the neighbourhood of the coccyx.

COCCYGEAL NERVE.—The *dorsal division of the coccygeal nerve* is very small, and separates from the ventral primary portion of the nerve in the sacral canal. It is joined by a communicating filament from the last sacral nerve, and ends in the ligamentous tissue over the posterior surface of the coccyx.

VENTRAL (ANTERIOR) BRANCHES OF THE SPINAL NERVES.

The ventral branches (*rami anteriores*) of the spinal nerves are distributed to the parts of the body situated in front of the vertebral column, including the limbs. They are, for the most part, considerably larger than the dorsal divisions, and each is connected by one or two slender filaments with the sympathetic. Those of the cervical, lumbar, and sacral nerves form plexuses of various forms; but those of the thoracic nerves remain for the most part separate from one another.

VENTRAL DIVISIONS OF CERVICAL NERVES.

The ventral divisions of the upper four cervical nerves form the cervical plexus. The first emerges between the rectus lateralis and rectus anticus minor muscles; and the others, having passed behind the vertebral artery and between the two intertransverse muscles, appear at the side of the neck between the scalenus medius and levator scapulæ muscles behind and the rectus anticus major muscles in front. They are each united by a communicating filament to the first cervical ganglion of the sympathetic nerve, or to the cord connecting that ganglion with the second.

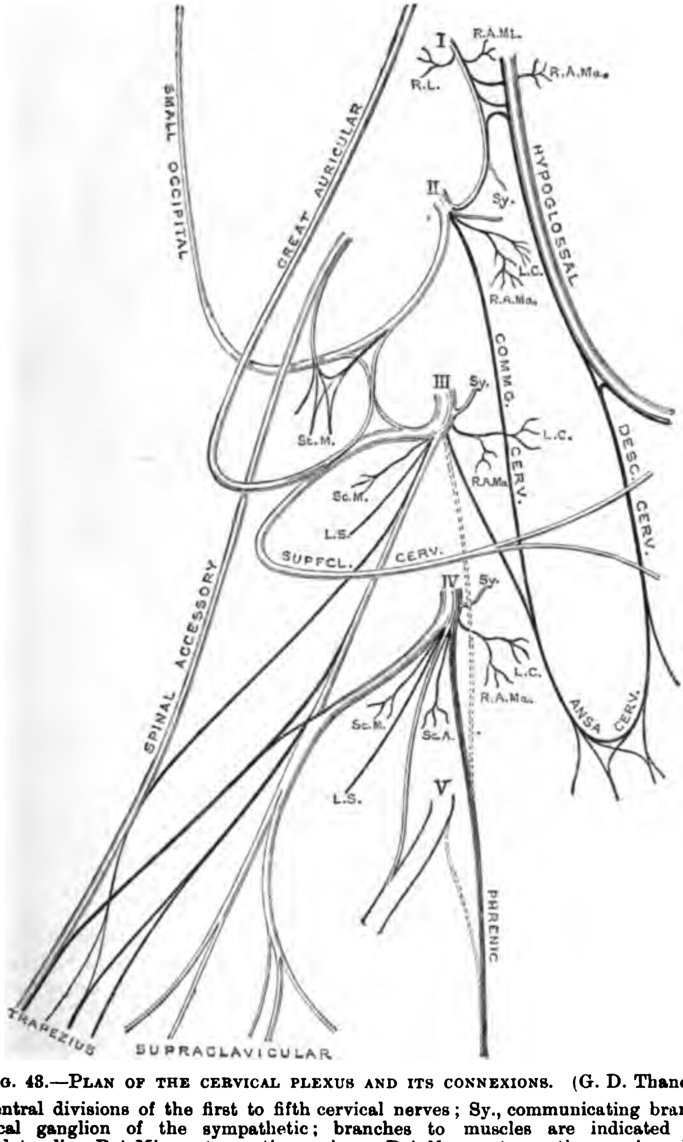
I
R.A.Mi.
R.L.
R.A.Ma.
SMALL OCCIPITAL
GREAT AURICULAR
HYPOGLOSSAL
II
Sy.
L.C.
R.A.Ma.
COMM G.
III
Sy.
St.M.
L.C.
CERV.
DESC. CERV.
R.A.Ma.
Sc.M.
L.S.
SUPFCL. CERV.
IV
Sy.
SPINAL ACCESSORY
L.C.
R.A.Ma.
ANSA CERV.
Sc.M.
Sc.A.
L.S.
V
PHRENIC
TRAPEZIUS
SUPRACLAVICULAR

FIG. 48.—PLAN OF THE CERVICAL PLEXUS AND ITS CONNEXIONS. (G. D. Thane.)

I to V, ventral divisions of the first to fifth cervical nerves; Sy., communicating branches to the upper cervical ganglion of the sympathetic; branches to muscles are indicated as follows: R.L., rectus lateralis; R.A.Mi., rectus anticus minor; R.A.Ma., rectus anticus major; L.C., longus colli; St.M., sternomastoid; Sc.A., scalenus anticus; Sc.M., scalenus medius; L.S., levator scapulæ.

The ventral divisions of the lower four cervical nerves, larger than the upper four, appear between the anterior and middle scaleni muscles, and, together with the larger part of the first thoracic, go to form the brachial plexus. They are each connected by a filament with one of the two lower cervical ganglia of the sympathetic, and with the plexus on the vertebral artery.

The ventral divisions of the first and second nerves require a notice separately from the description of the nerves of the cervical plexus.

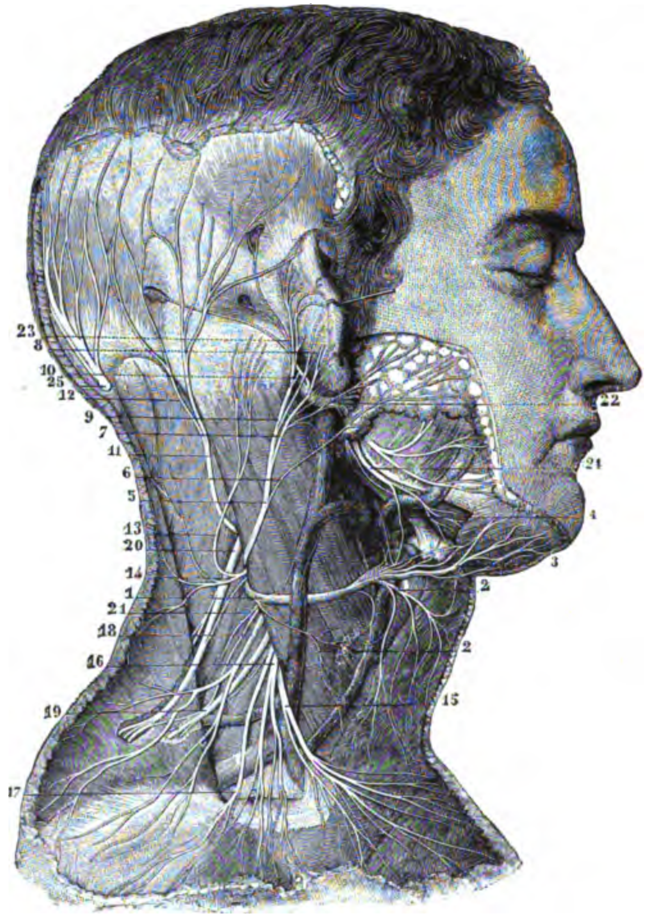

FIG. 44.—THE SUPERFICIAL BRANCHES OF THE CERVICAL PLEXUS.
(From Sappey, after Hirschfeld and Leveillé.) ⅓.

1, superficial cervical nerve (represented too large); 2, its inferior branch; 3, its superior branch; 4, its union with the facial; 5, great auricular nerve; 6, one of its facial branches; 7, its branch to the lobule; 8, twig which pierces the auricle to pass to its outer surface; 9, branch to the deep surface of the pinna; 10, its union with the posterior auricular of the facial nerve; 11, small occipital nerve; 12, its branch which unites with the great occipital nerve; 13, a mastoid branch arising separately from the plexus; 14, twigs from this to the back of the neck; 15, inner, 16, 17, middle, 18, outer branches of the supraclavicular nerves; 19, branch of the cervical nerves passing into the trapezius muscle; 20, accessory distributed to the same and receiving a uniting branch from the cervical nerves; 21, branch to the levator scapulæ; 22, trunk of the facial nerve; 23, its posterior auricular branch passing into the occipital and the posterior and superior auricular muscles; 24, its cervical branch; 25, great occipital nerve.

Suboccipital nerve.—The ventral branch of the first nerve runs forwards in a groove on the outer side of the upper articular process of the atlas, and bends downwards in front of the transverse process of that vertebra to join the second nerve. In this course forwards it lies beneath the vertebral artery, and on the inner side of the rectus lateralis muscle, to which it gives a branch. As it crosses the inner side of the foramen in the transverse process of the atlas, the nerve is joined by a filament from the sympathetic on the vertebral artery. From the loop which it makes in front of the transverse process, twigs are supplied to the two anterior recti muscles, and one or two larger branches pass to the hypoglossal trunk, in connexion with which most of the fibres pass down into the descending cervical nerve (p. 51). The loop is also united by short filaments to the superior cervical ganglion of the sympathetic and to the trunk-ganglion of the vagus.

Filaments of this nerve are distributed to the articulation of the occipital bone with the atlas, and, according to Valentin, also to the mastoid process of the temporal bone.

Second cervical nerve.—The ventral branch of the second cervical nerve, beginning between the arches of the first two vertebræ, is directed forwards between their transverse processes, passing round the outer side of the vertebral artery, and beneath the posterior intertransverse and other muscles fixed to those processes. In front of the intertransverse muscles, the nerve divides into an ascending part, which joins the first cervical nerve, and a descending part to the third.

Cervical plexus.—The cervical plexus is formed by the ventral divisions of the upper four cervical nerves, and distributes branches to some of the muscles of the neck and to a portion of the integument of the head, neck, and chest. It is placed opposite the first four vertebræ, beneath the sternomastoid muscle, and rests against the middle scalenus muscle and the levator scapulæ. The disposition of the nerves in the plexus is as follows: Each nerve, except the first, divides into an ascending and a descending part; and these are united in communicating loops with the contiguous nerves. From the union of the second and third nerves, superficial branches are supplied to the head and neck; and from the junction of the third with the fourth, arise some of the cutaneous nerves of the shoulder and chest. Muscular and communicating branches spring from the same nerves.

The branches of the plexus may be divided into two sets—a superficial and deep: the superficial consisting of those which perforate the cervical fascia and supply the integument; the deep comprising branches which are distributed for the most part to the muscles. The superficial nerves may be subdivided into ascending and descending; the deep nerves into an internal and an external series.

Superficial ascending branches of cervical plexus.—The **small occipital nerve** varies in size, and is occasionally double. It springs from the second and third (sometimes only the second) cervical nerves, and is directed almost vertically to the head along the posterior border of the sternomastoid muscle, giving off in its course twigs to the skin over the upper portion of the posterior triangular space. Having perforated the deep fascia near the cranium, the small occipital nerve ascends to the scalp between the ear and the great occipital nerve, and ends in cutaneous filaments which extend upwards to somewhat above the level of the ear. It communicates with branches from the great occipital, great auricular, and posterior auricular nerves, and it supplies an *auricular branch* which is distributed to the upper part of the ear on its inner aspect.

Varieties.—The small occipital nerve is sometimes directed backwards across the posterior triangle of the neck, and perforates the trapezius muscle close to its upper border, before ascending to the head. The auricular branch is occasionally derived from the great occipital nerve. The small occipital is sometimes much reduced in size and distributed solely to the skin of the neck, its place on the head being taken by branches of the great occipital nerve.

Great auricular nerve.—Arising from the second and third cervical nerves, this, the largest of the ascending branches of the plexus, winds round the hinder border of the sternomastoid, and is directed obliquely upwards between the platysma myoides muscle and the deep fascia of the neck towards the lobule of the ear. A little below the latter the nerve gives a few small offsets to the face, and then ends in auricular and mastoid branches.

The *auricular branches* are directed to the back of the auricle, on which they ramify, and are connected with twigs derived from the posterior auricular branch of the facial nerve. One offset reaches the outer surface of the ear by a fissure between the antihelix and the concha. With the small occipital it supplies the pinna and external auditory meatus behind a line prolonged downwards from near the highest part of the helix to the notch between the tragus and antitragus, except an area in the concha innervated by the auricular branch of the vagus.

The *mastoid branch* ramifies in the integument over the upper end of the sternomastoid muscle and the mastoid process, and communicates with the posterior auricular and small occipital nerves.

The *facial branches* are distributed to the integument of the face over the parotid gland and masseter muscle. Some slender filaments penetrate into the substance of the gland, and communicate with the lower division of the facial nerve.

Varieties.—The great auricular nerve may arise solely from the third, or from the third and fourth cervical nerves (Henle). The mastoid branch is often a separate offset of the plexus, ascending between the great auricular and small occipital nerves (fig. 44, 13).

Superficial cervical nerve (*nervus cutaneus colli*).—This nerve takes origin, usually in common with the great auricular, from the second and third cervical nerves, turns forwards over the sternomastoid muscle about the middle, and, after perforating the cervical fascia, divides beneath the platysma myoides into two branches, which are distributed to the anterior part of the neck.

The *upper branch* is the larger, and gives an ascending twig which accompanies the external jugular vein, and communicates freely with the cervical branch of the facial nerve; it is then transmitted through the platysma to the surface, and ramifies in the integument of the upper half of the front of the neck, filaments reaching as high as the mandible.

The *lower branch*, sometimes represented by two or three smaller offsets, likewise pierces the platysma and is distributed below the preceding, its filaments extending in front as low as the sternum.

Varieties.—The cervical cutaneous nerve also may arise from the third only, or from the third and fourth cervical nerves. It is sometimes represented by two or more branches arising separately from the plexus.

Superficial descending branches of cervical plexus.—The **supraclavicular nerves** arise together from the third and fourth cervical nerves, and descend in the interval between the sternomastoid and the trapezius muscles. As they approach the clavicle, they are three or more in number, and are recognised as *anterior*, *middle*, and *posterior*.

The *anterior branch* (suprasternal), which is much smaller than the rest, ramifies over and below the inner third of the clavicle, and terminates near the sternum. From it one or two filaments are furnished to the sternoclavicular articulation (Rüdinger, Hepburn).

The *middle branch*, generally divided into two or three parts, and crossing the clavicle in the interval between the sternomastoid and trapezius muscles, distributes some twigs over the fore-part of the deltoid, and others over the pectoral muscle as low as the third rib. The latter join the small anterior cutaneous branches of some of the upper intercostal nerves.

The *posterior branch* (supra-acromial) is directed outwards across the clavicular attachment of the trapezius muscle, and ramifies over the acromion and in the integument of the outer and back part of the shoulder.

Filaments from these nerves supply the skin over the lower part of the posterior triangular space, and one or two twigs pass backwards over the trapezius to the integument above the spine of the scapula.

Variety.—One of the middle branches of the supraclavicular nerves occasionally perforates the clavicle on its way downwards.

Deep branches of cervical plexus: internal series.—Connecting branches.—The cervical plexus is connected near the base of the skull with the vagus, hypoglossal, and sympathetic nerves, by means of filaments intervening between those nerves and the loop formed by the first two cervical nerves in front of the atlas (p. 63).

Muscular branches.—Branches to the prevertebral muscles proceed from the cervical nerves close to the vertebræ, including the loop between the first two of these nerves; and from the fourth nerve a twig is frequently given to the upper part of the scalenus anticus.

Two *communicating cervical branches*, one from the second, the other from the third cervical nerve, descend over or under the internal jugular vein to join the descending cervical nerve in the ansa cervicalis, from which the infrahyoid muscles are supplied (p. 51).

Variety.—In some cases there is also a communicating branch from the fourth nerve fig. 37).

Phrenic nerve.—The phrenic nerve (fig. 37, 9; fig. 46, 3) passes down through the lower part of the neck and the thorax to its destination. It arises mainly from the fourth cervical nerve, but it also receives, in the majority of instances, an additional root from either the third or the fifth nerve. While descending in the neck, the nerve inclines inwards over the anterior scalenus muscle; and near the chest it is joined by a filament from the middle or lower cervical ganglion of the sympathetic.

At the root of the neck each phrenic nerve is placed between the subclavian artery and vein, and crosses over the internal mammary artery from without inwards and backwards. It then takes a nearly vertical course, in front of the root of the lung on each side, and along the side of the pericardium—between this and the mediastinal part of the pleura. Near the diaphragm it divides into branches, which pass separately through the muscle, and then, diverging from each other, are distributed on the under surface.

The *right nerve* has a more direct course than the left, and lies from above downwards along the outer side of the right innominate vein, the superior vena cava, and the pericardium.

The *left nerve* is somewhat longer than the right, in consequence of the oblique position of the heart and pericardium round which it winds, and also because the diaphragm is lower on this than on the opposite side. It passes into the thorax between the left innominate vein and subclavian artery, and then crosses in front of the left vagus and over the left side of the arch of the aorta before reaching the pericardium.

Besides the terminal branches supplied to the diaphragm, each phrenic nerve gives on its way through the thorax filaments to the pleura and pericardium. Luschka describes also twigs from the lower part of the nerve to the peritoneum, and on the right side to the inferior cava and the right auricle of the heart.

One or two filaments of the nerve of the right side join in a small ganglion with branches to the diaphragm which are derived from the cœliac plexus of the sympathetic; and from the ganglion twigs are given to the suprarenal capsule, the hepatic plexus, and the lower vena cava. On the left side there is a junction between the phrenic and the sympathetic nerves near the œsophageal and aortic openings in the diaphragm, but without the appearance of a ganglion.

According to the observations of Pansini in animals,[1] the terminal ramifications of the phrenic nerves form in the diaphragm a complicated plexus, in which the last three intercostal nerves also take part. The plexus contains microscopic ganglia.[2]

Varieties.—The phrenic may receive an accessory root from the second or the sixth cervical nerve (rarely), from the descendens cervicis or the ansa cervicalis, or from the nerve to the subclavius (frequently). The last may be of considerable size; and in some instances the whole nerve has been found arising in this way and descending in front of the third part of the subclavian artery and the subclavian vein to the thorax. The *accessory phrenic nerve* is a filament arising from the fifth, or more rarely the fifth and sixth cervical nerves, and passing either in front of or behind the subclavian vein to join the trunk at the root of the neck or at a variable level in the thorax. The phrenic nerve, having a normal origin, has been observed in different cases lying along the outer border of, or piercing, the scalenus anticus, crossing in front of the subclavian vein, and passing through a ring formed by that vessel. It occasionally gives a branch to the scalenus anticus. Barton[3] reports a case where the phrenic nerve descended in contact with the posterior surface of the sternomastoid and crossed in front of the subclavian vein and right innominate vein, and was placed half an inch in front of the scalenus anticus and the subclavian artery.

Deep branches of cervical plexus: external series.—Muscular branches.—The sternomastoid receives a branch from the second cervical nerve. Two branches proceed from the third and fourth nerves to the levator scapulæ; and from the same nerves, as they leave the spinal canal, branches are given to the middle scalenus muscle. Further, the trapezius receives one or more considerable branches which arise from the third and fourth cervical trunks in common with the supraclavicular nerves.

Communications with the accessory nerve.—In the substance of the sternomastoid muscle, this nerve is connected with the branch of the cervical plexus furnished to that muscle. It is also connected with the branches distributed to the trapezius—the union between the nerves being beneath the muscle, and having the appearance of a plexus; and with another branch of the cervical plexus in the interval between the two muscles.

SUMMARY OF THE CERVICAL PLEXUS.—From the cervical plexus cutaneous nerves are distributed to the side of the head, to part of the pinna and external auditory meatus, to the face superficial to the parotid gland and masseter muscle, to the anterior two-thirds or more of the neck, and to the upper part of the chest and shoulder. The muscles supplied with nerves from the plexus are the sternomastoid, the trapezius, and the infrahyoid muscles, the anterior and lateral recti capitis, the longus colli, the levator scapulæ, the scalenus medius and anticus in part, and the diaphragm. By means of its branches the plexus communicates with the facial, vagus, accessory, hypoglossal, and sympathetic nerves.

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[1] Arch. ital. de Biologie, x. 1888.

[2] On sensory fibres in the phrenic nerve, see J. Ferguson, Brain, 1891.

[3] Trans. Roy. Acad. Med. Ireland, xvi.

Brachial plexus.—This large plexus, from which the nerves of the upper limb are supplied, is formed by the union of the ventral divisions of the four lower cervical and the greater part of the first thoracic nerves. It also receives in many cases a fasciculus from the lowest of the nerves (fourth) which go to form the cervical plexus, or a filament from the second thoracic nerve: these two roots may co-exist. The plexus extends from the lower part of the neck behind the clavicle to the axillary space, and terminates opposite the coracoid process of the scapula in large nerves for the supply of the limb.

The *cervical* or *supraclavicular portion* of the plexus, emerging from the cleft between the scalenus anticus and medius, lies in the lower part of the posterior triangular space, above and behind the third part of the subclavian artery: it is crossed by the posterior belly of the omohyoid muscle, and is often pierced by the transverse cervical or posterior scapular artery. After passing behind the clavicle, the *axillary* or *infraclavicular portion* of the plexus is placed to the acromial side of the axillary vessels, being enclosed in the axillary sheath, and covered by the pectoralis major and subclavius muscles; and at its termination it lies between the pectoralis minor and subscapularis muscles, and on each side of and behind the second part of the axillary artery.

The manner in which the nerves are disposed in the plexus is liable to some variation, but the following may be regarded as the typical arrangement, from which the different forms met with may in most cases be readily derived. The fifth and sixth cervical join

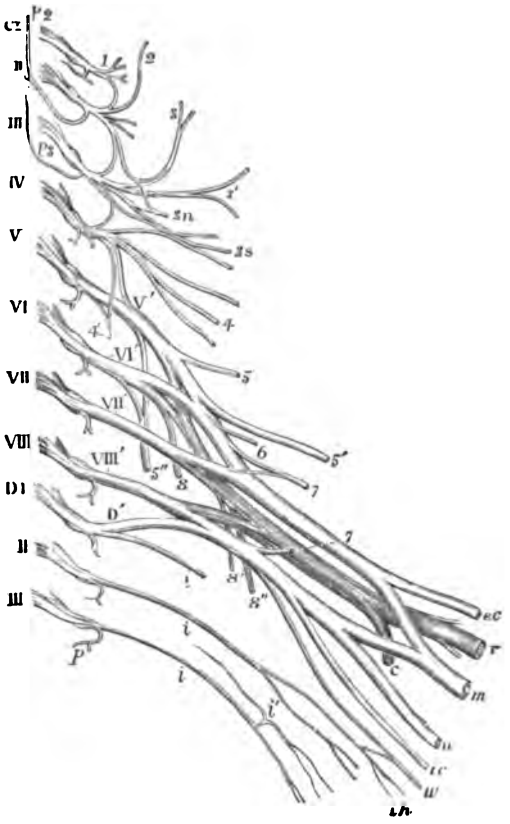

FIG. 45.—PLAN OF THE CERVICAL AND BRACHIAL PLEXUSES. (Allen Thomson.) ⅓.

The nerves are separated from the spinal cord at their origin and are supposed to be viewed from before: CI, the first cervical or suboccipital nerve, and the Roman numbers in succession from II to VIII the corresponding cervical nerves; DI, the first, and II and III the second and third thoracic nerves; the origin of the dorsal primary branch is shown in all the nerves; of these, *p* 2 indicates the great occipital from the second, and *p* 3 the smallest occipital nerve from the third. *Cervical plexus*: 1, ventral primary branch of the first cervical nerve and loop of union with the second nerve; 2, small occipital nerve; 3, great auricular nerve; 3', superficial cervical nerve; 3 *n*, communicating branches to the ansa cervicalis from the second and third; 3 *s*, communicating to the accessory from the third and fourth nerves; 4, supraclavicular nerves; 4', phrenic nerve. *Brachial plexus*: V' to VIII', and D', the five roots of the brachial plexus; 5, the rhomboid nerve; 5', suprascapular; 5'', posterior thoracic; 6, nerve to the subclavius muscle; 7, 7, inner and outer anterior thoracic nerves; 8, 8', 8'', subscapular and thoraco-dorsal nerves. In the larger nerves proceeding to the shoulder and arm from the plexus, those of the anterior divisions are represented of a lighter shade, those belonging to the posterior division darker; *ec*, musculo-cutaneous; *m*, median; *u*, ulnar; *ic*, internal cutaneous; *w*, lesser internal cutaneous; *r*, musculo-spiral; *c*, circumflex; *i*, *i*, intercostal nerves; *i'*, lateral branch of the same; *ih* intercosto-brachial nerve.

together at the outer border of the scalenus medius to form an *upper trunk*; similarly the eighth cervical and first thoracic unite together behind the anterior scalene muscle to form a *lower trunk*; while the seventh cervical remains single, forming a *middle trunk*.

Soon after passing the outer border of the scaleni muscles, each primary trunk divides into a ventral and a dorsal branch. This division is of special morphological significance, since it represents the separation of the fibres destined for the supply of the ventral cutaneous surface and the ventral muscles of the limb from the corresponding dorsal structures. If the connective tissue of the nerve-trunks is removed and their dorsal and ventral divisions followed upwards through the trunks, it will be seen that the

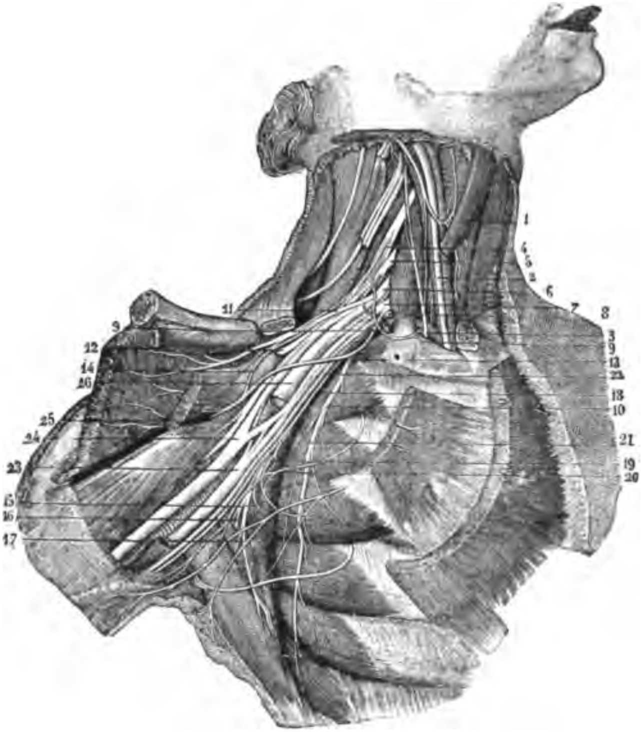

FIG. 46.—DEEP DISSECTION OF THE AXILLA, SHOWING THE BRACHIAL PLEXUS AND NEIGHBOURING NERVES. (From Sappey, after Hirschfeld and Leveillé.) ½.

The clavicle has been sawn through near its sternal end, and is turned aside with the muscles attached to it; the subclavius and the greater and lesser pectoral muscles have been removed from the front of the axilla. 1, ansa cervicalis; 2, vagus; 3, phrenic, passing down to the inner side of the scalenus anticus muscle; 4, ventral primary division of the fifth cervical nerve; 5, 6, 7, the same of the sixth, seventh, and eighth cervical nerves; 8, the same of the first thoracic nerve; 9, 9, nerve to the subclavius muscle, communicating with the phrenic nerve; 10, long thoracic nerve distributed to the serratus magnus; 11, external anterior thoracic nerve, passing into the great pectoral muscle; 13, internal anterior thoracic, distributed to the lesser pectoral; 14, twig of communication between these two nerves; 12, suprascapular nerve, passing through the suprascapular notch; 15, upper subscapular nerve; 16, lower subscapular nerve; 17, thoraco-dorsal nerve; 18, 21, small internal cutaneous nerve; 19, union of this with the second and third intercostal nerves; 20, lateral branch of the second intercostal; 22, internal cutaneous nerve; 23, ulnar nerve to the inside of the axillary artery, passing behind the vein, and having, in this case, a root from the outer cord of the plexus; 24, median nerve immediately below the place where its two roots embrace the artery, which is divided above this place; 25, musculo-cutaneous nerve, passing into the coraco-brachialis muscle, to which it is giving a branch; 26, musculo-spiral nerve, passing behind the divided axillary artery.

primary ventral division of each spinal nerve bifurcates in this way. In the case of the fifth and sixth nerves, however, the ventral branches are much larger than the dorsal, while in the case of the eighth cervical and first thoracic the reverse is the case, and occasionally the dorsal branch of the first thoracic is absent.

The ventral branches of the upper and middle trunks unite together to form the outer cord (*lateral fasciculus*) of the plexus; the large ventral branch of the lower trunk forms by itself the inner cord (*mesial fasciculus*) of the plexus; and the dorsal branches of all three trunks unite together to form the posterior cord (*posterior fasciculus*). The outer and inner cords thus contain ventral limb-fibres, and the posterior cord dorsal fibres. The cords lie at first in a single bundle on the outer side of the first part of the axillary artery, but lower down they are placed, the first on the outer side, the second on the inner side, and the third behind that vessel in its second part, whence they are continued into the principal nerves for the arm.

Varieties.—The most important variations in the origin of the plexus are dependent upon the level at which it arises; and two types are described—*prefixed*, or high, and *postfixed*, or low. The most extreme range of variation in this respect may involve nearly an entire nerve. In the prefixed type the fourth gives a fairly large branch to the plexus, the dorsal branch of the first thoracic is small, and there is no ascending branch from the second thoracic. In the postfixed type the branch from the fourth is absent, the dorsal branch of the first thoracic is fairly large, and the second thoracic sends a branch to the plexus. In man the brachial plexus is prefixed as compared with all the monkeys below the anthropoids.[1]

The seventh cervical nerve is sometimes divided into three branches, one passing to each of the three cords of the plexus. The posterior cord has been observed arising from the sixth, seventh, and eighth, and in one case only from the seventh and eighth cervical nerves (Turner). Cases are recorded in which the plexus consisted of only two cords, the larger one representing either the inner and outer, or the posterior and inner cords of the normal arrangement.

The fifth cervical nerve is not infrequently, the sixth more rarely, directed outwards through the fibres of the scalenus anticus; the fifth nerve may even pass altogether in front of that muscle.

Branches of the brachial plexus.—The nerves proceeding from the brachial plexus are usually divided into two classes—viz. (A) those that are given off from its supraclavicular part, and so arise before the formation of the three cords of the plexus; and (B) those arising below the clavicle from the outer, inner, and posterior cords.

To the former (supraclavicular) group belong some small muscular nerves to the scaleni and longus colli muscles, the nerve to the rhomboid muscles, the long thoracic nerve for the serratus magnus muscle, the suprascapular nerve, the nerve to the subclavius, and sometimes a branch to join the phrenic nerve.

The nerves given off below the clavicle are derived from the three great cords of the plexus in the following manner:

From the outer cord—the external of the two anterior thoracic nerves, the nerve to the coraco-brachialis, the musculo-cutaneous, and the outer head of the median.

From the inner cord—the inner of the two anterior thoracic nerves, internal cutaneous and lesser internal cutaneous, the ulnar, and the inner head of the median.

From the posterior cord—the subscapular, thoraco-dorsal, circumflex, and musculo-spiral.

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[1] Wilfrid Harris, Journ. Anat. and Phys. xxxvii

The following table shows the spinal nerves from which the several offsets of the plexus are commonly derived.[1] + signifies that the branch in question receives fibres from the spinal nerve in whose column the sign is placed; +? signifies that there is most frequently a root from that spinal nerve, but it may be wanting; ? signifies that the corresponding root is not unfrequently present, although exceptional. The rarer forms of variation are not taken into account.

	C. V.	C. VI.	C. VII.	C. VIII.	T. 1.
A. SUPRACLAVICULAR BRANCHES.					
a. To trunk-muscles:					
To longus colli	+?	+?	+?	+?	
To scaleni	+	+	?		
To phrenic nerve	?				
b. To limb-muscles:					
To rhomboidei	+				
To serratus magnus	+	+	+?		
Suprascapular	+	+?			
To subclavius	+	?			
B. INFRACLAVICULAR BRANCHES.					
a. From outer cord (lateral fasciculus):					
External anterior thoracic	+?	+	+		
To coraco-brachialis		+	+	+?	
Musculo-cutaneous	+	+			
Outer head of median		+	+		
b. From inner cord (mesial fasciculus):					
Internal anterior thoracic				+	+
Lesser internal cutaneous					+
Internal cutaneous				+	+
Ulnar			+?	+	+
Inner head of median			?	+	+
c. From posterior cord (posterior fasciculus):					
Upper subscapular	+	+			
Lower subscapular	+?	+	+?	?	?
Thoraco-dorsal		+?	+	?	
Circumflex	+	+?			
Musculo-spiral	+?	+	+	+	

Branches above the clavicle.—Small muscular branches.—The branches for the *scaleni* and *longus colli muscles* spring in an irregular manner from the lower cervical nerves close to their place of emergence from the intervertebral foramina.

Branch to the phrenic nerve.—This small branch is, when present, an offset from the fifth cervical nerve; it usually joins the phrenic nerve on the anterior scalenus muscle.

Varieties.—The communicating branch to the phrenic nerve has been seen to pass down into the thorax over the subclavian artery, and even over the vein, before joining with the trunk. A second filament to the phrenic, from the sixth nerve, is rarely met with.

The **nervus dorsalis scapulæ** (*branch for the rhomboid muscles*) arises in common with the highest root of the long thoracic nerve from the fifth nerve close to the vertebræ, and is directed backwards to the base of the scapula through the fibres of the middle scalenus, and beneath the levator scapulæ, to the deep surface of the rhomboid muscles, in which it terminates. It gives one or two branches to the levator scapulæ, and sometimes a twig to the highest digitation of the serratus posticus superior (Rieländer).

Varieties.—A. F. Dixon[2] found the nerve sending a branch through the trapezius to the skin close to the median line, at the level of the spinous processes of the fifth and sixth thoracic vertebræ.

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[1] W. P. Herringham, Proc. Roy. Soc. xli. 1886; Wilfrid Harris, Journn. Anat. and Phys. xxxviii.

[2] Journ. Anat. and Phys. xxx.

The **long thoracic nerve** (*external respiratory nerve of Bell*) usually arises by three roots from the fifth, sixth, and seventh cervical nerves. The upper and middle roots perforate the scalenus medius and join either in the substance or on the surface of that muscle; the lower root passes in front of the scalenus medius and joins the trunk opposite or below the first rib. The nerve descends behind the brachial plexus and the first part of the axillary artery, on the outer surface of the serratus magnus, nearly to the lower border of that muscle, supplying it with numerous branches. The fibres derived from the several roots are distributed to the slips of the muscle in order from above downwards.

Varieties.—The root from the seventh nerve is sometimes wanting. In three instances the nerve was found by Lucas receiving a fourth root from the eighth cervical nerve. The root from the fifth nerve sometimes remains separate, being distributed only to the upper division of the muscle.

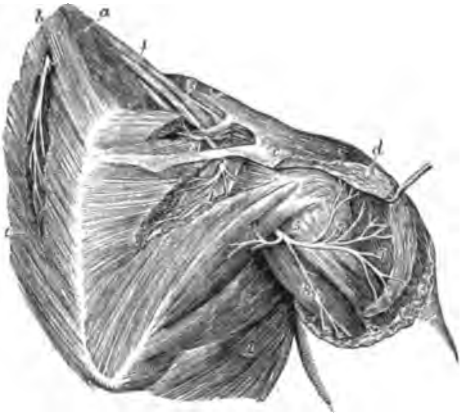

FIG. 47.—DISTRIBUTION OF THE SUPRASCAPULAR AND CIRCUMFLEX NERVES. (Hirschfeld and Leveillé.) $\frac{1}{5}$.

a, scalenus medius and posticus muscles; *b*, levator scapulæ; *c*, acromion; *d*, deltoid muscle, of which the back part has been removed; *e*, rhomboid muscles; *f*, teres major; *g*, latissimus dorsi; 1, the brachial plexus, seen from behind; 1′, nerve to the rhomboid muscles; 2, placed on the clavicle, the suprascapular nerve; 3, its branches to the supraspinatus muscle; 4, branch to the infraspinatus; 5, the circumflex nerve, passing out of the quadrangular interval; 6, its branch to the teres minor muscle; 7, branches to the deltoid; 8, cutaneous branch.

The **suprascapular nerve** arises from the trunk formed by the union of the fifth and sixth cervical nerves, but its fibres are derived mainly from the fifth nerve. It passes outwards and backwards beneath the trapezius and omohyoid muscles to the upper border of the scapula, where it enters the supraspinous fossa through the suprascapular notch, below the ligament of the same name. In the supraspinous fossa, the nerve supplies branches to the supraspinatus muscle, and a slender *articular* filament to the shoulder-joint; and it then descends through the great scapular notch to the lower fossa, where it ends in the infraspinatus muscle, furnishing sometimes a second twig to the articulation of the shoulder.

Varieties.—The suprascapular nerve is sometimes derived solely from the fifth nerve; or it may receive a few fibres from the fourth nerve. It has been seen dividing into two parts, one of which passes through the suprascapular notch, while the other pierces the bone just below the notch. Very rarely a branch is given to the upper part of the subscapularis muscle, or to the teres minor. Filaments to the acromio-clavicular articulation have been noticed by Rüdinger, and to the periosteum and substance of the scapula by Swan and Ellis.

The **nerve of the subclavius muscle,** a slender branch given off from the front of the upper trunk of the plexus, is also derived mainly or wholly from the fifth cervical nerve. It descends over the third part of the subclavian artery and behind the clavicle to the posterior surface of its muscle.

Varieties.—The nerve to the subclavius often sends a branch inwards to join the phrenic nerve either at the root of the neck (fig. 46) or, less frequently, in the thorax. A communicating twig to the external anterior thoracic nerve, and a branch to the clavicular head of the sterno-mastoid have also been observed (Turner).

Branches below the clavicle.—**Anterior thoracic nerves.**—The anterior thoracic nerves, two in number, supply the pectoral muscles.

The *external,* or more superficial branch, arising from the outer cord under cover of the clavicle, is derived from the sixth and seventh nerves, very frequently also the fifth. It crosses inwards over the axillary artery, and, after giving off a branch to join the inner nerve, terminates in the great pectoral muscle.

The *internal,* or deeper branch, springing from the inner cord, mostly receives fibres from both the last cervical and first thoracic nerves. It comes forwards between the axillary artery and vein, and is joined by the communicating branch from the external nerve, with which it forms a plexiform loop embracing the axillary artery. From this loop offsets proceed to the small and to the lower part of the large pectoral muscles.

Varieties.—The internal branch occasionally has no fibres from the first thoracic nerve. Cutaneous filaments from the anterior thoracic nerves to the mammary region and to the arm have been described by various observers. The external branch is said to supply twigs sometimes to the clavicular part of the deltoid; and, according to Bock and Valentin, a filament is given to the acromio-clavicular articulation.

Subscapular nerves.—The subscapular nerves are usually two in number, and supply the subscapularis and teres major muscles.

The *upper nerve,* the smaller of the two, is derived from the fifth and sixth cervical nerves, and penetrates the upper part of the subscapularis muscle. This branch is often double.

The *lower nerve* is derived from the fifth and sixth, or less frequently the sixth and seventh cervical nerves. It gives one or two branches to the lower part of the subscapularis, and ends in the teres major muscle.

Varieties.—The *upper nerve* occasionally proceeds from the fifth or sixth cervical nerve alone. The *lower nerve* seldom proceeds from the fifth or sixth nerve alone, or from the fifth, sixth, and seventh nerves. The branches to the lower part of the subscapularis and the teres major muscles are sometimes independent offsets of the brachial plexus. The nerve to the teres major is occasionally given off by the commencement of the circumflex nerve.

The **thoraco-dorsal nerve** (*long subscapular*) obtains its fibres mainly from the seventh, to a less extent in many cases also from the sixth or eighth cervical nerves. It descends in company with the subscapular artery to enter the deep surface of the latissimus dorsi muscle.

Varieties.—The most frequent origin of the thoraco-dorsal nerve is from the seventh alone, or from the seventh and eighth nerves; it rarely receives fibres from the fifth.

Circumflex nerve (*axillary*).—This is one of the terminal branches of the posterior cord of the plexus, and obtains its fibres from the fifth and sixth cervical nerves. It is placed at first behind the axillary artery, resting on the subscapularis muscle, at the lower border of which it turns backwards with the posterior circumflex vessels. It then appears at the back of the shoulder in the quadrilateral space between the two teres muscles (fig. 47), external to the long head of the triceps, and divides into branches, which are distributed to the deltoid and teres minor muscles, the integument of the shoulder, and the shoulder-joint.

The *upper branch* winds round the upper part of the shaft of the humerus, extending nearly as far as the anterior border of the deltoid muscle, to which it is distributed. One or two *cutaneous filaments* penetrate between the muscular fibres, and are bent downwards to supply the integument over the lower part of the muscle.

The *lower branch* supplies offsets to the back part of the deltoid, and furnishes the nerve to the teres minor, on which there is often a small reddish enlargement. It then turns round the posterior border of the deltoid below the middle, and ramifies in the integument over the lower two-thirds of that muscle, and over the adjacent part of the triceps (*nervus cutaneus brachii lateralis*).

One or two *articular filaments* for the shoulder-joint arise near the commencement of the nerve, and enter the capsular ligament below the subscapular muscle.

Rauber describes a filament of the upper branch as ascending in the bicipital groove to be distributed to the upper extremity of the humerus and the capsule of the shoulder-joint.

Varieties.—The circumflex nerve is occasionally derived wholly from the fifth cervical; and the contribution from the sixth nerve is often very small. It has been seen to perforate the lower part of the subscapularis muscle (Macalister, Bubenik), to which it often furnishes a branch. Branches to the long head of the triceps and to the infraspinatus are also mentioned.

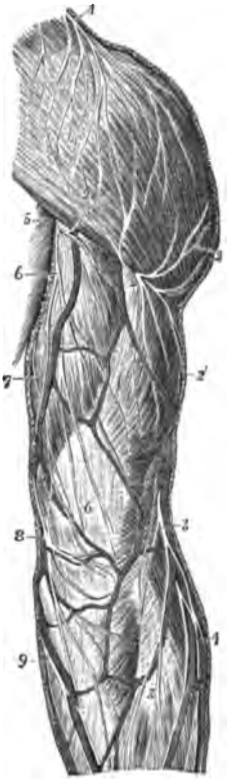

FIG. 48. — DISTRIBUTION OF THE POSTERIOR CUTANEOUS NERVES OF THE SHOULDER AND ARM. (Hirschfeld and Leveillé.) ⅓.

1, supra-acromial branches of the cervical plexus descending on the deltoid muscle; 2, ascending, and 2', descending cutaneous branches of the circumflex nerve; 3, inferior external cutaneous of the musculo-spiral nerve; 4, posterior cutaneous branches of the musculo-cutaneous nerve to the forearm; 5, 6, internal cutaneous of the musculo-spiral; 7, lesser internal cutaneous; 8, 9, posterior branches of the internal cutaneous nerve.

Internal cutaneous nerve (*nervus cutaneus antibrachii medialis*).—This nerve is composed of fibres proceeding from the first thoracic, and usually also from the eighth cervical nerve. After leaving the inner cord of the plexus, it is placed at first to the inner side of the axillary artery, and then descends superficially between the brachial artery and the basilic vein to rather below the middle of the arm, where it becomes subcutaneous. As it pierces the fascia it is divided into two parts, one destined for the anterior, the other for the posterior surface of the forearm.

The *anterior division* crosses at the bend of the elbow behind (less frequently over) the median basilic vein, and distributes filaments in front of the forearm, as far as the wrist; one of these may be joined with a cutaneous branch of the ulnar nerve (fig. 49 B, 14).

The *posterior division*, smaller than the anterior, inclines to the inner side of the basilic vein, and sends its branches obliquely backwards round the inner margin of the forearm to supply the skin about as far as the subcutaneous border of the ulna. Above the elbow this division is connected with the lesser internal cutaneous nerve; in the forearm it communicates with the anterior division, and near the wrist sometimes with the dorsal branch of the ulnar nerve.

One or more *branches to the integument of the arm* pierce the fascia near the axilla, and reach to the elbow, or nearly so, distributing filaments outwards over the biceps muscle.

Varieties.—The posterior division of the internal cutaneous nerve has been seen arising separately from the posterior branch of the lower trunk of the brachial plexus.[1] Cases are recorded in which the posterior division is joined, or replaced to a greater or less extent, by a branch of the ulnar nerve. In one instance the posterior branch was large and extended to the hand, taking the place of the absent dorsal branch of the ulnar nerve (Thane).

Lesser internal cutaneous nerve (*nervus cutaneus brachii medialis; nerve of Wrisberg*).—This nerve is derived from the first thoracic nerve, and commonly arises from the inner cord of the brachial plexus in union with the internal cutaneous nerve. In the axilla it lies at first behind the axillary vein, but it soon appears on the inner side of that vessel, and communicates with the intercosto-brachial nerve. It then descends along the inner side of the basilic vein to about the middle of the arm, where it pierces the fascia, and its filaments are thence continued to the interval between the internal condyle of the humerus and the olecranon.

Varieties.—The lesser internal cutaneous of the arm may receive fibres from the eighth cervical (rarely) or the second thoracic nerve. The *connexion with the intercosto-brachial nerve* presents much variety in different cases: in some there are two or more intercommunications, forming a kind of plexus on the posterior boundary of the axillary space; in others the intercosto-brachial nerve is of larger size than usual, and takes the place of the median cutaneous of the arm, only receiving in the axilla a small filament from the brachial plexus, and this small communicating filament represents in such cases the median cutaneous of the arm. It sometimes communicates also with the lateral cutaneous branch of the third intercostal nerve. Absence of the lesser internal cutaneous of the arm is noted. Birmingham[2] reports several cases in which, where the lesser internal cutaneous was absent as a branch of the inner cord of the brachial plexus, it was represented by a lateral cutaneous which arose from the first thoracic and pierced the first intercostal space.

The **nerve to the coraco-brachialis** is a small branch formed by fibres derived from the seventh cervical nerve. In the infant it is a separate offset from the outer cord of the plexus, but in the adult it is commonly more or less closely united to the trunk of the musculo-cutaneous nerve, from which it separates before that nerve enters the muscle (Herringham). It is often represented by two filaments.

Musculo-cutaneous nerve.—The musculo-cutaneous or external cutaneous nerve, derived from the fifth and sixth cervical nerves, is deeply placed between the muscles as far as the elbow, and below that point is immediately under the integument. Arising from the outer cord of the brachial plexus opposite the small pectoral muscle, it perforates the coraco-brachialis, and, passing obliquely across the arm between the biceps and brachialis anticus muscles, reaches the outer side of the biceps a little above the elbow. Here it perforates the fascia, and, passing behind the median cephalic vein, divides into two branches which supply the integument on the outer side of the forearm, one on the anterior, the other on the posterior aspect.

Branches in the arm.—In addition to the one or two twigs to the coraco-brachialis which may be given off from this nerve near its origin (see above), the musculo-cutaneous furnishes the following offsets in the deep part of its course:

Branches to the biceps and *brachialis anticus* muscles, which arise after the nerve has pierced the coraco-brachialis.

A slender *branch to the humerus*, entering the bone with the medullary artery.

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[1] G. Elliot Smith, Journ. Anat. xxix. 85.

[2] Journ. Anat. and Phys. xxx.

An *articular filament* to the elbow-joint.

The nerve to the humerus is described by Rauber and others as arising from the nerve before it enters the coraco-brachialis, and descending along the brachial artery, to which it supplies filaments ; but Testut states that in all the cases in which he found this branch it was given off by the nerve to the brachialis anticus. An articular filament may proceed from the nerve to the biceps (Cruveilhier) or from that to the brachialis anticus (Rüdinger) ; Testut traced a twig from the latter source to the periosteum about the coronoid fossa. A *vascular branch* to the lower part of the brachial artery rom the nerve of the brachialis anticus is described by Swan and Testut.

Branches in the forearm.—The *anterior branch* descends near the radial border of the forearm. It is placed in front of the radial artery near the wrist, and distributes its terminal offsets over the thenar eminence. One or two filaments pierce the fascia and run on the artery to the articulations of the wrist. This part of the nerve is connected above the wrist with a branch of the radial nerve.

The *posterior branch* is directed outwards to the back of the forearm, and ramifies in the integument of the lower two-thirds, extending as far as or somewhat beyond the wrist. It communicates with a branch of the radial nerve, and with the lower external cutaneous branch of the musculo-spiral nerve.

Varieties.—The musculo-cutaneous nerve proper occasionally receives fibres from the seventh cervical nerve.

In some cases the constituent fibres of the nerve remain adherent to the outer head and trunk of the median for a variable distance in the upper part of the arm, the musculo-cutaneous or its several branches then being given off from the median trunk, and passing outwards to the interval between the biceps and brachialis anticus muscles : this is a common arrangement in lower mammals. In other cases (2 per cent., Testut ; 8 per cent., Villar) only a part of the fibres take this course, so that a communicating branch runs from the median to the musculo-cutaneous (fig. 50A, 5) ; or the muscular part of the nerve perforates the coraco-brachialis and the cutaneous part is given off from the median (Schwalbe) ; or the median furnishes only the muscular branches (Villar). Much more frequently (36 per cent., Testut) some of the median fibres are associated with the musculo-cutaneous in its passage through the coraco-brachialis, a communicating branch then passing from the latter nerve to the median. Very rarely the whole outer cord of the plexus pierces the coraco-brachialis, and then divides into musculo-cutaneous and outer head of median.[1]

Sometimes the musculo-cutaneous nerve does not perforate the coraco-brachialis, in which case it may pass either behind that muscle, or between the coraco-brachialis and the short head of the biceps. The nerve has also been seen perforating the short head of the biceps, or the brachialis anticus, as well as the coraco-brachialis.

In rare cases a branch is given to the pronator teres muscle. The terminal portion of the nerve is not unfrequently continued on the back of the hand to the skin over the first metacarpal bone and the adjoining interosseous space. Hepburn found the musculo-cutaneous supplying the back of the thumb in a case in which the radial nerve was wanting; and H. Virchow and Th. Kölliker describe a case in which it gave the dorsal digital nerves to both sides of the ring and the radial side of the little fingers.

Summary.—The musculo-cutaneous nerve supplies the biceps and brachialis anticus muscles, the integument on the outer side of the forearm, the humerus, and the elbow- and wrist-joints. Communications are established between it and the lower external cutaneous branch of the musculo-spiral and the radial.

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[1] Testut, 'Recherches anatomiques sur l'anastomose du nerf musculo-cutané avec le nerf median,' Journ. de l'Anat. 1883 ; and 'Mémoire sur la portion brachiale du nerf musculo-cutané,' Internat. Monatschr. f. Anat. 1884 ; F. Villar, 'Quelques recherches sur les anastomoses des nerfs du membre supérieur,' Bull. Soc. Anat. de Paris, 1888.

Ulnar nerve.—The ulnar nerve, the largest branch of the inner cord of the brachial plexus, receives its fibres from the last cervical and first thoracic nerves. From its origin, where it is placed between the axillary artery and vein, it descends on the inner side of the main artery of the limb as far as the middle of the arm, and thence with the inferior profunda artery along the back of the internal intermuscular septum, being often lodged in a groove in the substance of the inner head of the triceps muscle, to the interval between the olecranon and the inner condyle of the humerus. In the arm it is covered only by the fascia, and it may be felt through the integument a little above the elbow. It next passes between the two heads of the flexor carpi ulnaris muscle, under cover of which it is continued with a straight course as far as the wrist,

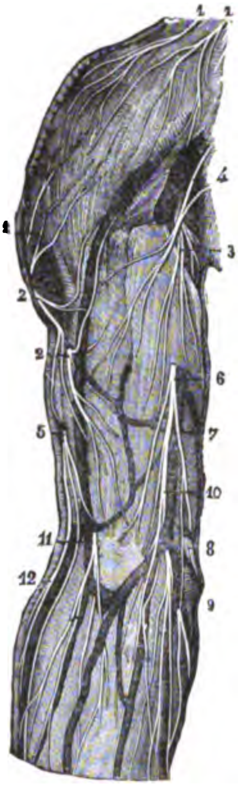

FIG. 49A.—ANTERIOR CUTANEOUS NERVES OF THE SHOULDER AND ARM. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{6}$.

1, 1, supraclavicular nerves from the cervical plexus; 2, 2, 2, cutaneous branches of the circumflex nerve; 3, 4, upper branches of the internal cutaneous nerve; 5, upper external cutaneous branch of the musculo-spiral; 6, internal cutaneous nerve piercing the deep fascia; 7, its posterior branch; 8, communicating twig with one of the anterior branches; 9, 10, anterior branches of this nerve, some turning round the median basilic and ulnar veins; 11, musculo-cutaneous nerve descending (exceptionally) over the median cephalic vein; 12, lower external cutaneous branch of the musculo-spiral nerve.

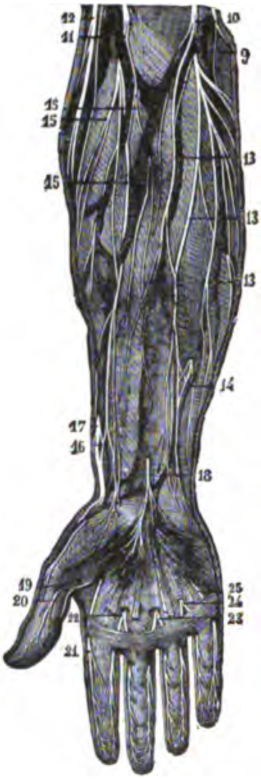

FIG. 49B.—ANTERIOR CUTANEOUS NERVES OF THE FOREARM AND HAND. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{6}$.

9, 10, 13, distribution of the anterior division of the internal cutaneous nerve; 14, union of one of these with a twig of the ulnar nerve; 12, lower external cutaneous branch of the musculo-spiral nerve; 11, 15, distribution of the external cutaneous nerve; 16, union of one of its branches with 17, the radial nerve; 18, palmar cutaneous branch of the median nerve; 19, 20, internal and external digital branches to the thumb from the median nerve; 21, external digital to the index finger; 22, 23, digital branches to the index, middle, and ring fingers; 24, 25, digital branches from the ulnar nerve to the ring and little fingers.

resting on the flexor profundus digitorum. The nerve meets the ulnar vessels somewhat above the middle of the forearm, and from this point it remains in contact with them on their inner side. Above the wrist it gives off a large dorsal branch to the hand, and the trunk then runs over the front of the annular ligament, being placed between the ulnar artery and the pisiform bone, to terminate as it enters the palm by dividing into superficial and deep parts.

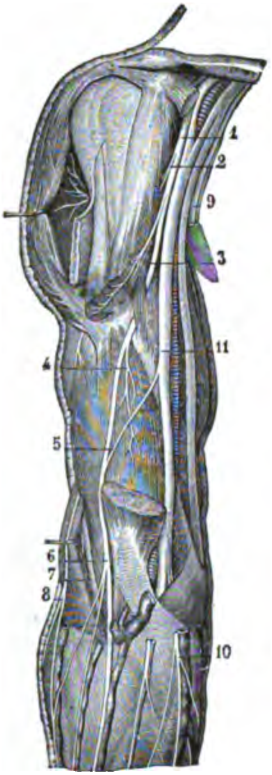

FIG. 50A.—DEEP VIEW OF THE ANTERIOR NERVES OF THE SHOULDER AND ARM. (From Sappey, after Hirschfeld and Leveillé.) ½.

1, musculo-cutaneous nerve, giving off, 2, the branch to the coraco-brachialis muscle; 3, branch to the biceps, represented incorrectly as given off before the nerve pierces the coraco-brachialis; 4, branch to brachialis anticus; 5, communicating branch from the median to the musculo-cutaneous nerve (an infrequent variety); 6, continuation of the nerve to its cutaneous distribution; 7, radial nerve in the interval between the brachialis anticus and brachio-radialis muscles; 8, inferior external cutaneous branch of the musculo-spiral; 9, the internal cutaneous nerves of arm and forearm divided; 10, anterior branch of the internal cutaneous of the forearm; 11, median nerve; to the inner side of this the ulnar nerve is crossed by the line from 11.

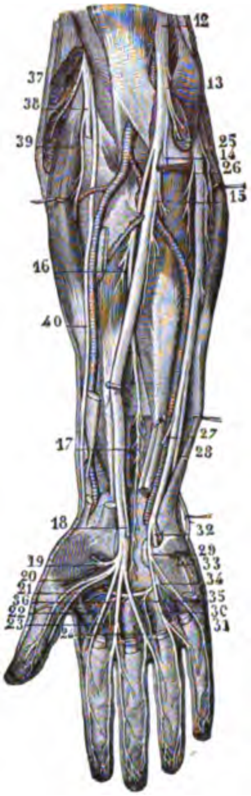

FIG. 50B.—DEEP VIEW OF THE ANTERIOR NERVES OF THE FOREARM AND HAND. (From Sappey, after Hirschfeld and Leveillé.) ½.

12, median nerve; 13, its branch to the pronator teres; 14, branch to the superficial flexor muscles, which have been removed; 15, branch to the flexor profundus digitorum; 16, branch to the flexor longus pollicis; 17, anterior interosseous nerve; 18, palmar cutaneous branch cut short; 19, branch to short muscles of thumb; 20, 21, digital branches to thumb; 22, 23, 24, third, fourth, and fifth digital branches; 25, branch given by ulnar nerve to flexor carpi ulnaris; 26, branch to flexor profundus digitorum; 27, cutaneous twig; 28, dorsal branch of ulnar; 29, superficial palmar portion; 30, 31, digital branches to ring and little fingers; 32, deep palmar branch; 33, its branch to short muscles of little finger; 34, 35, 36, twigs given by deep branch of ulnar to third and fourth lumbricales, all the interosseous muscles, and the adductors of the thumb.

The ulnar nerve usually gives off no branches in the upper arm.

Branches in the forearm.—Articular filaments are given to the elbow-joint as the nerve passes behind it.

Muscular branches (8 *c*, 1 *t*[1]) arise from the nerve near the elbow, and pass to the flexor carpi ulnaris and the inner half of the flexor profundus digitorum muscles.

Cutaneous branches.—These two small nerves arise about the middle of the forearm by a common trunk. One pierces the fascia, and turning downwards joins a branch of the internal cutaneous nerve of the forearm: this branch is often absent. The second, a *palmar branch*, lies on the ulnar artery, which it accompanies to the hand. This little nerve gives filaments around the vessel, and ramifies in the integument of the inner part of the palm, joining in some cases with other cutaneous offsets of the ulnar or median nerve.

Dorsal branch to the hand.—This large offset (8 *c*), leaving the trunk of the ulnar nerve two or three inches above the wrist, winds backwards beneath the flexor carpi ulnaris, gives a twig over the back of the wrist which usually joins in a loop with an offset of the radial nerve, and then divides into branches: one of these ramifies on the inner side of the little finger; another divides to supply the contiguous sides of that finger and the ring finger; a third supplies in part the contiguous sides of the ring and middle fingers, and usually communicates with the branch of the radial passing to the same interspace; while a fourth is distributed to the skin of the metacarpal region of the hand, often extending to the base of the index finger (fig. 50B). The dorsal digital branches on the little finger reach as far as the nail; on the ring finger they do not usually reach beyond the second phalanx. On the sides of the fingers they form communications with the corresponding volar digital nerves.

Branches in the palm.—The *superficial part* of the ulnar nerve (1 *t*, or 8 *c*, 1 *t*) supplies filaments to the palmaris brevis muscle and the integument of the hypothenar eminence, and divides into two *digital branches*. One of these passes to the ulnar side of the little finger; the other is connected in the palm of the hand with the innermost digital branch of the median nerve, and at the cleft between the little and ring fingers divides into the collateral nerves for these fingers. From the communicating branch with the median nerve filaments are sent to the skin and vessels of the palm. The terminal disposition of the digital branches on the fingers is the same as that of the median nerve, to be presently described.

The *deep part* (8 *c*) sinks backwards with the deep branch of the ulnar artery between the abductor and flexor brevis minimi digiti muscles, and passing to the inner side of and below the hook of the unciform bone (which it sometimes grooves[2]), through the cleft in the opponens minimi digiti muscle, follows the course of the deep palmar arch across the hand. It supplies the short muscles of the little finger as it passes between them; as it lies over the metacarpal bones it distributes branches to all the interosseous muscles and the inner two lumbricales; and at the outer side of the palm it terminates in offsets to the adductores pollicis and the inner head of the flexor brevis pollicis. *Articular filaments* pass upwards to the wrist, and others descend to the metacarpo-phalangeal articulations (Rüdinger). Rauber also describes small *perforating branches*, which accompany the superior perforating arteries in the interosseous spaces, and join the terminal filaments of the posterior interosseous nerve.

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[1] These numbers and letters indicate the nerve-roots from which the nerves under description receive fibres. Thus 8 *c*, 1 *t* = eighth cervical and first thoracic.

[2] W. Anderson, Proc. Anat. Soc. Feb. 6, 1894.

Varieties.—The ulnar nerve not infrequently has an additional root from the seventh cervical nerve. It is rarely derived wholly from the eighth nerve, or from the seventh and eighth cervical. In a few instances the nerve has been seen descending in front of the inner condyle instead of behind. Cases are also recorded in which the ulnar nerve slipped forwards over the internal condyle when the elbow was bent. A branch may pass from the ulnar nerve in the arm to reinforce the internal cutaneous (p. 74). A communication between the ulnar and median nerves in the arm was seen by Villar, and also a communication with the musculo-spiral.[1] A branch from the median to join the ulnar in the forearm is of frequent occurrence. When the occasional epitrochleo-anconeus muscle is present, it receives a branch from the ulnar nerve. Filaments of the ulnar nerve have been found passing to the inner part of the triceps, or to the flexor sublimis digitorum, and from the deep part to the second lumbricalis (H. St. John Brooks, Testut), or to the first lumbricalis (J. T. Wilson), or to the outer head of the flexor brevis pollicis (normal according to Swan and Brooks). The dorsal branch may be smaller than usual, or even absent, in which case the deficiency is generally compensated by the radial nerve (p. 85), in rare cases by the lower external cutaneous of the musculo-spiral (p. 83), or by the internal cutaneous (p. 74). Its area of digital distribution is seldom increased, but it was found by Hepburn supplying all four fingers in a case of absence of the radial nerve. Its filaments often reach to the radial side of the second metacarpal bone, and in one instance they were followed by Zander to the back of the first phalanx of the thumb.

SUMMARY.—The ulnar nerve gives cutaneous filaments to the lower part of the forearm (to a small extent), and to the inner part of the hand on its palmar and dorsal aspects. It supplies the following muscles—viz. the ulnar flexor of the carpus, the deep flexor of the fingers (its inner half), the short muscles of the little finger with the palmaris brevis, the interosseous muscles of the hand, the inner two lumbricales, the adductores pollicis, and the deep head of the flexor brevis pollicis. Lastly, it contributes to the nervous supply of the joints of the elbow, wrist, and hand.

Median nerve.—The median nerve, composed of fibres proceeding from the lower three cervical and the first thoracic nerves, arises by two roots or heads, one from the outer, the other from the inner cord of the brachial plexus. The outer head contains fibres derived from the fifth, sixth, and seventh cervical nerves, the inner head from the eighth cervical and first thoracic. Commencing by the union of these roots in front or on the outer side of the axillary artery, the nerve descends in contact with the brachial artery, lying on its antero-lateral aspect as far as the middle of the arm, then gradually passes inwards over it, and near the elbow gains the inner side of the vessel. Sinking into the hollow at the bend of the elbow, the nerve passes beneath the superficial portion of the pronator teres (but over the deep slip of that muscle, by which it is separated from the ulnar artery), and continues straight down the front of the forearm between the flexor sublimis and flexor profundus digitorum muscles. Arrived near the wrist it lies beneath the fascia, between the tendons of the flexor sublimis and palmaris longus internally and that of the flexor carpi radialis externally. It then enters the palm behind the annular ligament, and rests on the flexor tendons. Somewhat enlarged, and of a slightly reddish colour, it here separates into two parts of nearly equal size. One of these (the external) supplies some of the short muscles of the thumb, and gives digital branches to the thumb and the index finger; the second portion supplies the middle finger, and in part the index and ring fingers.

The median nerve usually gives no branch in the upper arm.

(*A*) *Branches in the forearm.*—*Articular branches.*—These are one or two filaments to the front of the elbow-joint (Rüdinger).

Muscular branches arise either together or separately in the neighbourhood of the elbow and pass to the pronator teres (6 *c*), flexor carpi radialis (6 *c*), palmaris longus and the condylo-ulnar head of the flexor sublimis digitorum

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[1] Bull. Soc. Anat. Paris, 1888, p. 613.

(7, 8 *c*, 1 *t*). A separate offset enters the radial head of the flexor sublimis, and a third branch supplying the index-finger belly of the same muscle is given off by the trunk at a lower level in the forearm.

Anterior interosseous nerve (7, 8 *c*, 1 *t* or 8 *c*, 1 *t*).—This is the longest branch of the median nerve, and it supplies the deeper muscles of the front of the forearm. Leaving the main trunk a little below the elbow, it runs downwards with the artery of the same name on the interosseous membrane to the deep surface of the pronator quadratus muscle, in which it ends. It distributes branches to the flexor longus pollicis and the outer half of the flexor profundus digitorum, between which it lies; a slender branch is given off to the interosseous membrane, along or in which it descends, dividing into two, and supplying filaments to the membrane, to the anterior interosseous vessels, to the shafts of the radius and ulna with the medullary arteries, and to the periosteum; and from the lower end of the nerve a twig is continued to the front of the wrist-joint. Small Pacinian bodies are found on the branches passing to the bone and periosteum (Rauber).

The *palmar cutaneous branch* arises a variable distance above the wrist, and pierces the fascia of the forearm between the tendons of the flexor carpi radialis and palmaris longus, close to the annular ligament, to terminate in the integument of the palm, where it communicates with the palmar cutaneous branch of the ulnar nerve. Some filaments are distributed over the thenar eminence, and form communications with twigs of the radial or external cutaneous nerve.

(*B*) *Branches in the hand.—Branch to muscles of the thumb.*—This short nerve (6 *c*), arching outwards immediately below the annular ligament, subdivides into branches for the abductor, the opponens, and the outer head of the flexor brevis pollicis muscles.

Digital nerves.—These are five in number, and belong to the thumb and the fingers as far as the outer side of the ring finger. They lie at first beneath the superficial palmar arch and its digital branches, but as they approach the clefts between the fingers they are close to the integument in the intervals between the longitudinal divisions of the palmar fascia, and on the fingers the nerves lie in front of the vessels.

The *first* and *second nerves* lie along the sides of the thumb; and the former (the outer one) is connected with the radial nerve over the border of the thumb.

The *third*, destined for the radial side of the index finger, gives a branch to the first or most external lumbricalis muscle.

The *fourth* supplies the second lumbricalis, and divides into collateral branches for the adjacent sides of the index and middle fingers.

The *fifth*, the most internal of the digital nerves, is connected by a cross-branch with the ulnar nerve, and divides to supply the adjacent sides of the ring and middle fingers. It often gives a branch to the third lumbricalis, which then has a double supply.

Each digital nerve divides at the end of the finger into two branches, one of which supplies the ball on the fore-part of the finger, while the other ramifies in the pulp beneath the nail. Branches pass from each nerve forwards and backwards to the integument of the finger; those passing backwards join the dorsal collateral nerve, and supply mainly the integument over the second and third phalanges of the middle three digits. Filaments are also furnished to the articulations of the fingers. The volar digital branches of the median and ulnar nerves are beset with numerous Pacinian corpuscles both in the palm and on the fingers: the number of these bodies varies from 60 to 100 in each digit.

Varieties.—Occasionally the median nerve does not receive any fibres from the first thoracic nerve.

Either of the heads of the nerve may be double. The level at which the two heads join is very variable: they have been found separate to the middle of the arm, and in one case nearly as far as the elbow (Testut). Calori saw the two heads embracing the axillary vein as well as the artery. The inner head may cross behind, instead of in front of, the axillary artery. The whole nerve is often found passing behind the brachial artery. The outer head has been seen by Turner passing behind the axillary artery, so that the trunk of the nerve lay altogether to the inner side of the brachial artery; and in another case recorded by the same anatomist the outer head separated from the musculo-cutaneous in the middle of the arm and crossed behind the brachial artery to join the inner head. Gruber and Walsh have described cases in which the nerve entered the forearm over the pronator teres muscle. It has also been seen running down the forearm superficial to the flexor sublimis digitorum (Thane). The nerve has been found split for a certain distance in the forearm, the cleft giving passage to the ulnar artery (Testut) or a branch of that vessel (Mauclaire), or to the superficial long head of the flexor longus pollicis (Davies-Colley, Taylor and Dalton, J. W. Williams), or to a supernumerary long palmar muscle (Reid and Taylor).

The frequent communication between the median and musculo-cutaneous nerves in the arm has already been referred to (p. 75). One instance is recorded of a connexion between the median and ulnar nerves in the arm (p. 79). A communication between these nerves in the upper part of the forearm is present in the proportion of one in four or five limbs, usually in the form of a branch leaving the median in common either with the muscular offsets at the elbow or with the anterior interosseous nerve, and passing with or near the ulnar artery to join the ulnar nerve about the middle of the forearm: less frequently the connexion is by means of a loop or small plexus, from which twigs are given off to the flexor profundus digitorum muscle: this communication between the median and ulnar nerves in the upper part of the forearm is normal in most apes (Hepburn, Höfer), and in lower mammals (Bardeleben). A communication in the lower part of the forearm is rare. In two cases a branch was seen passing from the median nerve at the elbow, over the superficial muscles, to join the ulnar (T. J. Jeans). Very seldom a branch runs from the ulnar to the median trunk or to its anterior interosseous branch. The communicating branch between the median and ulnar nerves in the palm is commonly directed from the ulnar to the median, but it may run in the opposite direction, or the communication may be looped or plexiform in arrangement. Absence of the communication has been noted. In two cases described by Klint the anterior interosseous nerve received a branch from the musculo-spiral (posterior interosseous?) through the interosseous membrane. A communication between the anterior and posterior interosseous nerves at the lower end of the interosseous space is noticed by Martin and Rauber.[1]

The digital nerves in the palm are often pierced by the corresponding arteries. Four cases are recorded by Gruber in which the nerve supplying the adjacent sides of the middle and ring fingers arose from the trunk in the forearm. A branch from the median nerve to the first dorsal interosseous muscle was observed by Brooks.

SUMMARY.—The median nerve gives cutaneous branches to the palm, and to three and a-half fingers. It supplies the pronator muscles, the flexors of the carpus and the long flexors of the fingers (except the ulnar flexor of the carpus, and part of the deep flexor of the fingers), likewise the outer set of the short muscles of the thumb, and two lumbricales. Articular filaments are also given to the joints of the elbow, wrist, and fingers.

A great similarity will be observed in the distribution of the median and ulnar nerves. Neither gives any offset in the arm. Together they supply all the muscles of the front of the forearm and in the hand, and together they supply the skin of the palmar surface of the hand, and impart tactile sensibility to all the digits.

Musculo-spiral (radial) nerve.—The musculo-spiral nerve, the largest offset from the brachial plexus, is derived from the sixth, seventh, and eighth cervical nerves, in some cases also from the fifth. It occupies chiefly the back part of the limb, and supplies nerves to the extensor muscles, as well as to the skin.

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[1] See also F. Curtis, Internat. Monatschr. f. Anat. u. Hist. iii. 1886; Third Annual Report of Committee of Collective Investigation of the Anat. Soc., by Arthur Thomson, Journ. Anat. xxvii. 1892.

Arising behind the axillary vessels from the posterior cord of the brachial plexus, of which it is the principal continuation and the only branch of that cord prolonged into the arm, it soon turns backwards with the superior profunda artery between the long and internal heads of the triceps, and runs beneath the external head of that muscle, in the hinder part of the spiral groove of the humerus, to the outer side of the arm. It then pierces the external intermuscular septum, and descends in the interval between the brachio-radialis and brachialis anticus muscles nearly to the level of the outer condyle of the humerus, where it ends by dividing into a superficial (radial) and a deep (posterior interosseous) branch. Of these, the superficial is altogether a cutaneous nerve, while the deep is the muscular nerve of the back of the forearm.

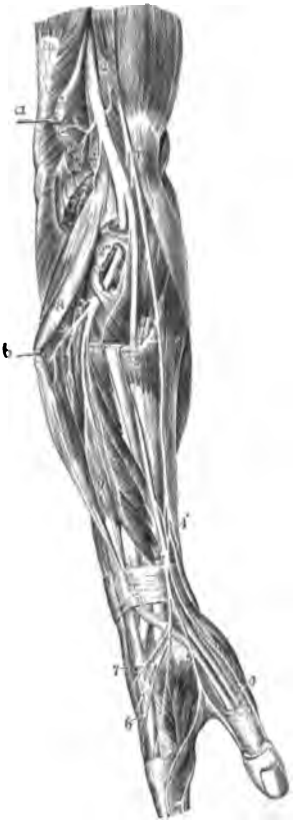

FIG. 51.—VIEW OF THE RADIAL SIDE OF THE FOREARM, SHOWING THE FINAL DISTRIBUTION OF THE MUSCULO-SPIRAL NERVE. (Hirschfeld and Leveillé.) ¼.

The brachio-radialis and the radial extensors have been divided, and their upper parts removed; the extensor communis digitorum is pulled backwards, and the supinator has been partially dissected to show the posterior interosseous nerve passing through it.

1, on the tendon of the biceps muscle, the musculo-cutaneous nerve; 1′, near the wrist, the lower part of this nerve and its plexus of union with the radial nerve; 2, trunk of the musculo-spiral nerve in the interval between the brachialis anticus, on which the number is placed, and the brachio-radialis; 2′, its muscular twigs to the brachio-radialis and long radial extensor; 2″, the posterior interosseous nerve passing through the substance of the supinator; 3, placed upon the cut lower portion of the brachio-radialis, and, lower down, the radial nerve; 4, the external digital nerve of the thumb; 5, digital nerves of the forefinger and thumb arising in common; 6, the same of the fore and middle fingers; 7, twig of union with the dorsal branch of the ulnar nerve; 8, placed upon the common extensor of the fingers, the muscular branches of the posterior interosseous nerve to the long extensor muscles; 9, upon the extensor longus pollicis, the branches to the short extensor muscles.

The branches of the musculo-spiral nerve may be classified according as they arise on the inner side of the humerus, behind that bone, or on the outer side.

A. Internal branches.—*Muscular branches* for the long and inner heads of the triceps (7, 8 *c*). That for the inner head gives two or three filaments to the upper part of the muscle, and then descends by the side of the ulnar nerve, to which it is often closely adherent for a part of its course, and enters the lower short fibres of the head. This long filament is named by Krause the *ulnar collateral branch.*

The *internal cutaneous branch* of the musculo-spiral nerve (*nervus cutaneus brachii posterior*) (8 *c*), often united in origin with the preceding, winds backwards beneath the intercosto-brachial nerve, and extends, supplying filaments to the skin over the long head of the triceps, nearly as far as the olecranon. This nerve is accompanied by a small cutaneous artery.

B. Posterior branches.—These consist of a fasciculus of *muscular branches* (7, 8 *c*) which supply the outer and inner heads of the triceps muscle and the anconeus. The *branch of the anconeus* is slender, and remarkable for its length; it descends in the substance of the inner head of the triceps to reach its destination.

C. External branches.—The *external cutaneous branches,* two in number, arise before the nerve pierces the external intermuscular septum, and become superficial just below the middle of the arm, between the outer head of the triceps and the brachialis anticus muscles.

The *upper branch* (6 *c*), the smaller of the two, is directed downwards to the fore-part of the elbow, along the cephalic vein, and distributes filaments to the lower half of the arm on its outer and anterior aspect. The *lower branch* (*n. cutaneus antibrachii dorsalis*) (6 *c*, or 6, 7 *c*, or 7 *c*, or 7, 8 *c*) descends in the interval between the external condyle and the olecranon, and reaches as far as the wrist, distributing its offsets to the lower half of the arm, and to the forearm, on their posterior aspect. It is connected near the wrist with a branch of the external cutaneous nerve, and often with the dorsal branch of the ulnar nerve. In some cases this branch is prolonged to the back of the hand (fig. 52, A).

Muscular branches are furnished to the brachio-radialis (6 *c*), extensor carpi radialis longior (6, 7 *c*) (the extensor carpi radialis brevior usually receiving its nerve from the posterior interosseous), and frequently a small twig to the outer part of the brachialis anticus (6 *c*), as the nerve lies between those muscles. Together with these branches *articular filaments* are given to the outer part of the elbow-joint.

According to Rauber, a branch of the musculo-spiral nerve is given regularly to the periosteum on the back of the humerus; and in some cases it also furnishes the nerve to the shaft of that bone, when the principal medullary artery is derived from the superior profunda. Filaments are described as passing to the elbow-joint also from the ulnar collateral nerve, and from the branch to the anconeus.

Varieties.—The musculo-spiral nerve has been seen passing backwards through the quadrilateral space between the teres muscles with the circumflex nerve.[1] A communication with the ulnar nerve in the arm is recorded by Villar (p. 79). The lower external cutaneous branch was traced by Brooks in one case to the first phalanx of the ring and the second phalanx of the little fingers; and it has been observed furnishing the dorsal digital nerves of the little and the ulnar half of the ring fingers in the place of the ulnar nerve (Gruber, Gegenbaur).

The **radial nerve** (*superficial radial*) receives its fibres from the sixth cervical nerve, sometimes also from the fifth or seventh. Continuing straight down from the musculo-spiral nerve, it lies a little to the outer side of the radial artery along the anterior border of the extensor radialis brevior, under cover of the brachio-radialis, and resting on the supinator (brevis), the insertion of the pronator teres, and the radius. About three inches above the wrist the nerve turns backwards beneath the tendon of the brachio-radialis and becomes subcutaneous. It then divides into two branches, which ramify on the back of the hand in the following manner:

The external portion passes to the radial side of the thumb, and is joined by an offset of the musculo-cutaneous nerve. It distributes filaments over the thenar eminence.

The internal portion communicates with the posterior branch of the musculo-cutaneous nerve in the forearm, sends an offset to the back of the wrist, which usually joins in an arch with the dorsal branch of the ulnar nerve, and then divides into four branches for the thumb and the outer two fingers. One of these supplies the ulnar side of the thumb, the second passes to the radial side of the index finger, the third divides for the adjacent sides of the index and middle fingers, and the fourth is directed to the interspace between the middle and ring fingers. In their course these branches supply twigs to the skin of the outer part of the back of the hand; and the innermost one crosses, and usually communicates with the outer branches of the dorsal ulnar nerve.

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[1] Guy's Hosp. Rep. xliv.

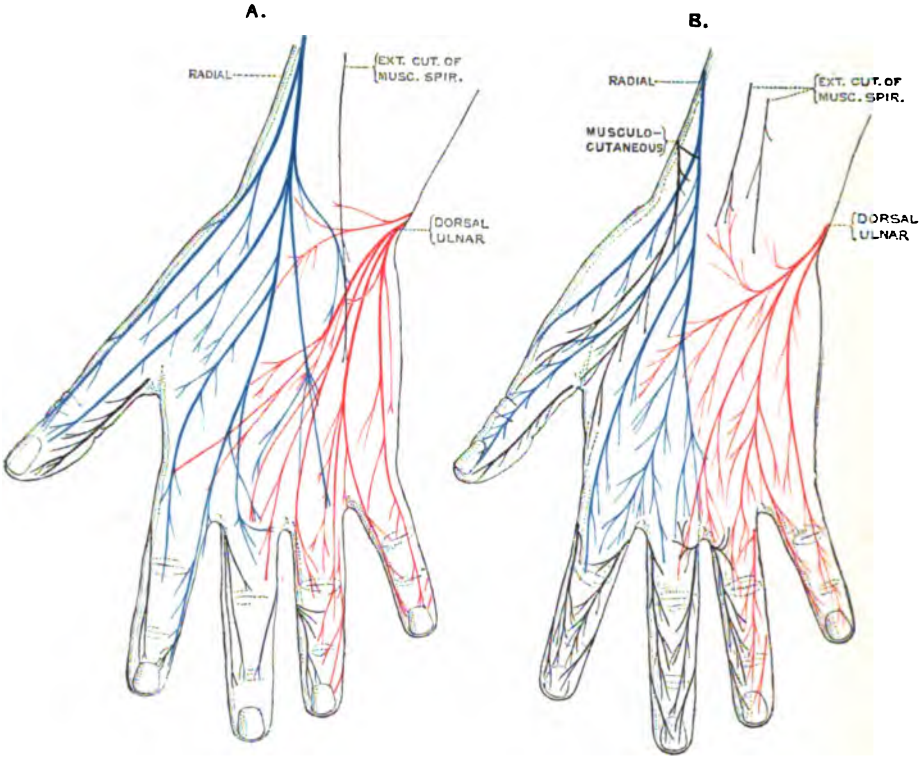

Fig. 52.—Dorsal cutaneous nerves of the hand. (A, after Brooks; B, after Hédon.)

The radial nerve is shown in blue, the branches of the ulnar in red, offsets of the musculo-cutaneous, musculo-spiral, and median in black. The two figures illustrate variations in the cutaneous supply. In A, the radial and ulnar nerves overlap to a considerable extent, and the lower external cutaneous of the musculo-spiral extends to the back of the hand. In B, the overlapping of the radial and ulnar nerves is slight, and the musculo-cutaneous is prolonged independently into the hand.

The distance to which the branches of the radial nerve extend varies in the several digits. On the thumb they reach to the nail, on the index finger to the second phalanx, and on the middle finger only to the first phalanx, while from the innermost branch filaments pass to the base of the ring finger.

From the dorsal digital nerves twigs are said to be given to the carpo-metacarpal, metacarpo-phalangeal, and first interphalangeal articulations; and according to Hédon, filaments pass forwards through the interosseous spaces to the skin of the palm. Lejars describes an offset from the outer division of the radial nerve to the abductor pollicis muscle.[1]

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[1] Bull. Soc. Anat. Paris, 1890, p. 488.

Varieties.—The area of distribution of the radial and the ulnar nerves, and the degree to which they overlap on the back of the hand, as well as the extent of the dorsal nerves on the three middle fingers, are subject to much variability. From observations in man and mammals Hédon and Zander conclude that the primitive arrangement is that in which the radial nerve supplies three and a-half digits and the ulnar one and a-half, all the digital branches extending to the nail. The reduction of the dorsal nerves on the three middle fingers appears to be an arrangement peculiar to man, in whom, however, the nerves are not unfrequently continued to the nail in the index and ring fingers, but very rarely in the middle finger.[1]

Occasionally the radial nerve supplies the whole of the back of the hand and fingers. Its outer division often gives a branch to the palm. Absence of the radial nerve was met with by Hepburn, the musculo-cutaneous supplying the thumb, and the ulnar nerve all the four fingers.[2]

Posterior interosseous nerve (*deep radial*).—This nerve, the larger of the two divisions of the musculo-spiral, is composed of fibres derived from the sixth and seventh, sometimes also the eighth, cervical nerves. It winds to the back of the forearm round the outer side of the radius, traversing the cleft in the supinator muscle, and is prolonged between the deep and superficial layers of the extensor muscles to somewhat below the middle of the forearm, where it sinks beneath the long extensor of the thumb, and reaches the lower part of the interosseous membrane.

Much diminished in size by the separation of numerous branches for the muscles, the nerve lies at the back of the wrist beneath the tendons of the extensor indicis and the common extensor of the fingers, and forms here a small enlargement, from which filaments are given to the adjoining ligaments and articulations.

Muscular branches.—Before the nerve passes to the back of the forearm it gives offsets to the extensor carpi radialis brevior (6, 7 *c*) and the supinator (6 *c*) muscles. After perforating the supinator, it supplies branches (7 *c*) to the extensor communis digitorum, extensor minimi digiti, extensor carpi ulnaris, the three extensors of the thumb, and the extensor indicis.

Articular branches. — From the terminal enlargement of the nerve fine twigs proceed to the articulations of the wrist, and, according to Rüdinger and Rauber, other filaments descend on the back of the hand to the metacarpo-phalangeal articulations.

Varieties.—The posterior interosseous nerve may pass over, instead of perforating, the supinator muscle (Luschka, Krause). A branch to the anconeus muscle is described by the same anatomists. There may be a communication between the anterior and posterior interosseous nerves at the lower part of the interosseous space (p. 81). In two cases, recorded by Turner and by Schwalbe, the posterior interosseous nerve passed down to supply the adjacent sides of the index and middle fingers; a similar condition has been found in the chimpanzee, orang, and gibbon (Westling, Hepburn, Höfer).

SUMMARY.—The musculo-spiral nerve supplies the extensor muscles of the elbow-joint, and frequently sends a filament to the brachialis anticus, which, however, receives its principal supply from another source. Before separating into its two large divisions, the nerve gives branches to two muscles of the forearm—viz. the brachio-radialis, and the long radial extensor of the carpus. Its deep division distributes nerves to the remaining muscles on the outer and back part of the forearm, except the anconeus (previously supplied)—viz. to the supinator and the extensors.

Cutaneous nerves are distributed, from the trunk of the nerve and its superficial division, to the upper arm, to the forearm, and to the hand—on the posterior and outer aspect of each. Articular branches are furnished to the elbow, wrist, metacarpo-phalangeal, and first interphalangeal joints.

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[1] H. St. John Brooks, Internat. Monatschr. f. Anat. u. Phys. v. 1888; E. Hédon, Internat. Monatschr. f. Anat. u. Phys. vi. 1889; R. Zander, Anat. Anz. iv. 1889.

[2] Journ. Anat. xxii. 511.

VENTRAL DIVISIONS OF THORACIC NERVES.

The ventral divisions of the twelve thoracic (dorsal) nerves are distributed almost entirely to the walls of the thorax and abdomen. The exceptions are the first, the greater part of which joins the brachial plexus, and the second and twelfth, which send cutaneous offsets to the arm and hip respectively. Close to the intervertebral foramina, these nerves are connected with the gangliated cord of the sympathetic by very short communicating branches; they are then directed transversely outwards to their destination without forming any plexus, and in this respect they differ from the ventral primary divisions of the other spinal nerves. The smaller part of the first, and the trunks of the succeeding ten nerves pass forwards in the intercostal spaces, and are thence termed *intercostal nerves.* Of these, the upper six are confined to the parietes of the thorax, while the lower five are continued anteriorly from the intercostal spaces into the wall of the abdomen. The twelfth nerve, sometimes distinguished as the *subcostal nerve,* is placed below the last rib, and is therefore contained altogether in the abdominal wall.

First thoracic nerve.—The ventral division of the first thoracic nerve divides into two parts, the larger of which ascends over the neck of the first rib to enter into the brachial plexus. The remaining portion of the nerve is continued as the *first intercostal,* a small branch which lies at first under cover of the first rib, and then courses along the first intercostal space, in the manner of the other intercostal nerves, but has usually no lateral cutaneous branch, and may also want the anterior cutaneous.

Variety.—The first thoracic nerve frequently receives a connecting twig which passes upwards in front of the neck of the second rib from the second nerve. This branch was found by Cunningham in twenty-seven out of thirty-seven dissections; it was of variable size, but generally very small, and it sometimes joined only one, in other cases both, of the divisions of the first nerve.[1]

Upper or pectoral intercostal nerves.—In their course to the forepart of the chest, these nerves accompany the intercostal blood-vessels. From the intervertebral foramina they are directed outwards in front of the superior costo-transverse ligaments, the levatores costarum and the external intercostal muscles; being covered anteriorly, as far as the angles of the ribs, only by the pleura and the thin layer of connective tissue known as the endothoracic fascia. Gaining the upper part of the corresponding intercostal spaces, where they are placed below the intercostal vessels, the nerves next run between the external and internal intercostal muscles, and soon give off the large *lateral cutaneous* branches, which accompany the prolongations of the trunks for a short distance, and then bend outwards through the external intercostal muscles about midway between the spine and the sternum. The nerves themselves, much reduced in size, are now continued forwards amid the fibres of the internal intercostal muscles as far as the costal cartilages, where they again come into close relation with the pleura. In approaching the sternum they cross in front of the internal mammary vessels and the triangularis sterni; and finally they pierce the internal intercostal muscles and the greater pectoral, to end in the integument of the breast, receiving the name of *anterior cutaneous nerves of the thorax.*

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[1] Journ. Anat. xi. 539.

Muscular branches are furnished by the intercostal nerves in the first part of their course to the levatores costarum, and, from the upper four nerves, to the serratus posticus superior. Several twigs enter the intercostal muscles with which the nerves are in relation. At the fore-part of the chest the triangularis sterni is supplied by offsets of these nerves from the second or third to the sixth; and from the sixth or the seventh nerve branches pass to the thoracic segment of the rectus abdominis after passing forwards between two costal cartilages (Bardeen).

Minute *subcostal branches* perforate the internal intercostal muscles to reach the inner surface of the ribs, where they are distributed to the periosteum and bone, as well as probably to the costal pleura (Testut); and, according to Luschka, fine *sternal twigs* are given off at the anterior ends of the intercostal spaces to the back of the sternum.

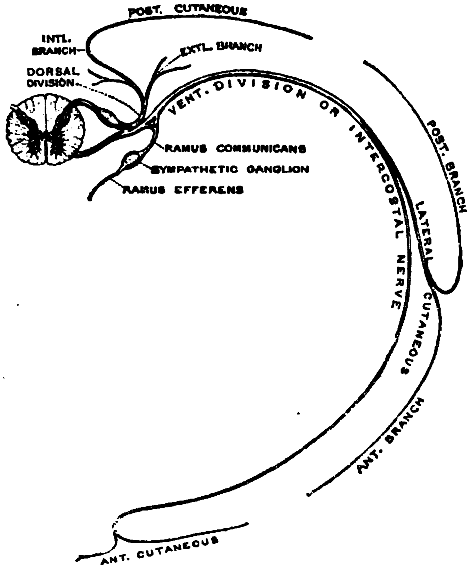

FIG. 53.—PLAN OF AN UPPER THORACIC NERVE. (G. D. Thane.)

The *lateral cutaneous nerves of the thorax* pierce the external intercostal and serratus anticus (magnus) muscles, in a line a little behind the pectoral border of the axilla. The first intercostal usually gives no lateral branch, or only a slender twig to the axilla, but when that of the second nerve is unusually small, it may be supplemented by a branch of the first. The branch from the second intercostal is named *intercosto-brachial,* and requires separate description. Each of the remaining lateral cutaneous nerves divides into two branches, which reach the integument at a short distance from each other, and are named *anterior* and *posterior.*

The *anterior branches* are continued forwards over the border of the great pectoral muscle. In the female their terminal ramifications supply the skin over the mamma, and some filaments enter the substance of the gland. From the lowest two nerves twigs are supplied to the upper digitations of the external oblique muscle of the abdomen.

The *posterior branches* turn backwards to the integument over the scapula and the latissimus dorsi muscle. The branch from the third nerve ramifies in the axilla, and a few filaments often reach the arm.

The **intercosto-brachial nerve** (*intercosto-humeral*), the lateral cutaneous branch of the second intercostal nerve, corresponds with the posterior of the two divisions of the succeeding lateral cutaneous branches, the anterior being commonly wanting. It crosses the axillary space to reach the arm, and is connected in the axilla with an offset of the lesser internal cutaneous. Penetrating the fascia, it becomes subcutaneous, and ramifies in the integument of the upper half of the arm on the inner and posterior aspect; a few filaments reach the integument over the scapula. The branches of this nerve cross over the internal cutaneous offset of the musculo-spiral, and a communication is established between the two nerves. The size of the intercosto-brachial nerve, and the extent of its distribution, are in inverse proportion to the size of the other cutaneous nerves of the upper arm, especially the lesser internal cutaneous.

The *anterior cutaneous nerves of the thorax*, which are the terminal twigs of the intercostal nerves, are reflected outwards in the integument over the great pectoral muscle. One or two of the upper branches may be connected with the supraclavicular nerves. In the female, those from the second, third, and fourth nerves are distributed over the mammary gland.

Varieties.—At the hinder part or side of the chest some of the adjacent intercostal nerves are occasionally connected by filaments which cross the inner surfaces of the ribs, passing from one intercostal space to join the nerve in the interval next below. A twig from the second intercostal nerve to the pectoralis major has been described by Swan and M. Flesch; one to the pectoralis minor by Brooks.

Lower or abdominal intercostal nerves.—The lower intercostal nerves in the first part of their course have relations like those of the upper nerves already described. Lying between the external and internal intercostal muscles, they give off the lateral cutaneous branches, and at the fore-part of the intercostal spaces they penetrate the internal intercostal muscles. They then pass between the slips of origin of the diaphragm, the seventh, eighth, and ninth nerves each crossing behind the cartilage of the rib below, and enter the abdominal wall. Here they are continued between the internal oblique and transversalis muscles as far as the outer edge of the rectus, diverging from one another as they pass inwards, in consequence of the increasing obliquity of the lower nerves. Finally, perforating the posterior layer of the sheath of the rectus, they turn forwards through the substance of that muscle and the anterior layer of its sheath to end in small cutaneous branches (*anterior cutaneous nerves*). While between the abdominal muscles the lower three or four nerves are united by loops of communication, and sometimes form a small plexus.

Muscular branches are given to the levatores costarum, to the serratus posticus inferior (from the ninth, tenth, and eleventh nerves), to the subcostal and intercostal muscles, and to the abdominal muscles with which the nerves are in contact. In addition to the five abdominal intercostal nerves, the rectus abdominis is usually supplied by branches from the sixth and twelfth thoracic nerves. Of these seven nerves, five enter the muscle above the level of the tendinous insertion opposite the umbilicus. Filaments are also described as passing from these nerves to the costal portion of the diaphragm.[1]

The *lateral cutaneous nerves of the abdomen* pass to the integument through the external intercostal and external oblique muscles, in a line with the corresponding nerves on the thorax, and divide in the same manner into anterior and posterior branches.

The *anterior branches* are the larger. They supply the digitations of the external oblique muscle, and are then directed inwards, the lower nerves also inclining downwards, in the superficial fascia, with small cutaneous arteries, nearly to the edge of the rectus muscle.

The *posterior branches* bend backwards over the latissimus dorsi.

The *anterior cutaneous nerves of the abdomen* are uncertain in number and position. There are generally two or three twigs from each nerve, and some of them perforate the rectus near its outer border, but the greater number issue near the linea alba. The branches of the seventh nerve emerge near the lower end of the ensiform process, and those of the tenth usually supply the skin about the umbilicus.

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[1] Cavalie, Journ. de l'Anatomie et de la Physiologie, xxxii.

Last thoracic nerve.—The ventral primary division of the last thoracic nerve is directed outwards in company with the abdominal branch of the first lumbar artery along the lower border of the twelfth rib. It passes beneath the

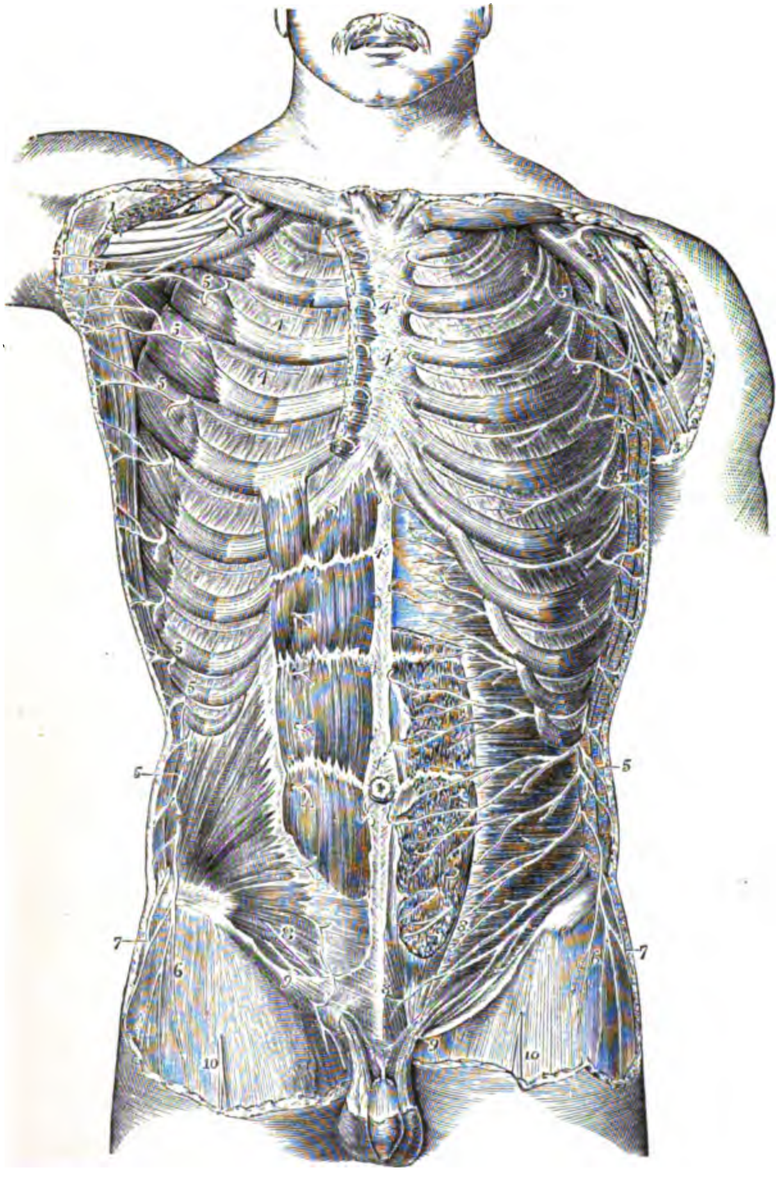

FIG. 54.—VIEW OF THE VENTRAL DIVISIONS OF THE THORACIC AND SOME OF THE OTHER SPINAL NERVES FROM BEFORE. (Hirschfeld and Leveillé.) ⅓.

The pectoralis major and minor muscles have been removed; on the right side the rectus abdominis and internal oblique muscles are shown; on the left side the anterior part of the rectus is cut away, and the transversalis is exposed.

1, median and other nerves of the brachial plexus; 2, lesser internal cutaneous; 3, intercosto-brachial; 4, intercostal nerves continued forwards to 4′, their anterior cutaneous twigs; 5, lateral cutaneous branches of these nerves; 6, lateral cutaneous branch of the last thoracic nerve; 7, iliac branch of the ilio-hypogastric nerve; 8, hypogastric branch of the same; 9, ilio-inguinal; 10, middle cutaneous of the thigh.

external arcuate ligament of the diaphragm, across the front of the quadratus lumborum, and at the outer border of the latter muscle it perforates the posterior aponeurosis of the transversalis (middle layer of the lumbar fascia), to follow a course similar to that of the lower intercostal nerves in the abdominal wall. It is usually connected near its origin with the first lumbar nerve by means of a small cord, which descends on or through the substance of the quadratus lumborum muscle. It supplies branches to the quadratus lumborum (frequently), internal oblique, transversalis, rectus, and pyramidalis muscles, as well as lateral and anterior cutaneous branches; and it sometimes communicates in the abdominal wall with the ilio-hypogastric nerve. Its anterior cutaneous twigs are distributed below a point midway between the umbilicus and pubis.

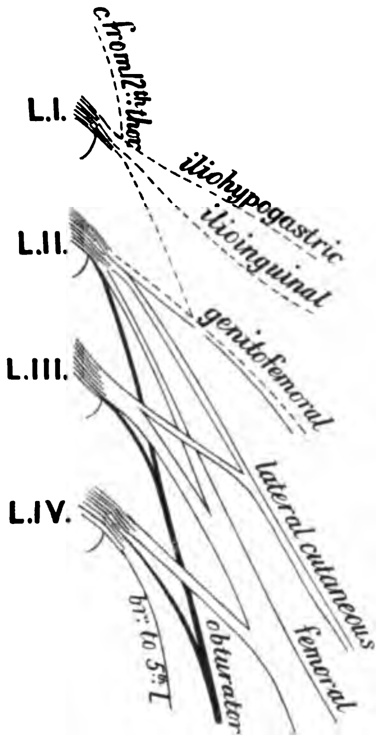

Fig. 55.—Diagram of the lumbar plexus from behind. (J. Symington.)

The branches to the trunk are indicated by interrupted lines. The dorsal offsets of the plexus to the limbs are represented light, and the ventral offsets dark.

The *lateral cutaneous branch* of the last thoracic nerve is usually of considerable size. It pierces the internal oblique muscle, gives a branch to the lowest slip of the external oblique, and then emerging through the latter muscle a variable distance (from one to three inches) above the iliac crest, is directed downwards to the integument of the fore-part of the gluteal region, some filaments reaching as far as the great trochanter.

Varieties.—In some cases the lateral cutaneous branch of the last thoracic nerve is small, and is distributed entirely to the skin above the iliac crest, its place over the hip being taken by the iliac branch of the ilio-hypogastric nerve. Complete absence of this branch was observed by M. Griffin four times in fifty cases.[1]

VENTRAL DIVISIONS OF LUMBAR NERVES.

The ventral divisions of the lumbar nerves increase in size from the first to the fifth. The upper three and the greater part of the fourth enter the lumbar plexus; the smaller part of the fourth and the fifth pass down to the sacral plexus. On leaving the intervertebral foramina, the nerves are connected by filaments with the cord of the sympathetic, these filaments being longer than those connected with other spinal nerves, in consequence of the position of the lumbar sympathetic ganglia on the fore-part of the bodies of the vertebræ. In the same situation small twigs are furnished to the quadratus lumborum muscle from the first and, sometimes, the second nerve, and to the psoas from the second and third nerves.

Lumbar plexus.—The lumbar plexus is formed by the ventral primary divisions of the upper four lumbar nerves. It is placed in the substance of the psoas muscle, in front of the transverse processes of the corresponding vertebræ. Above, the plexus is narrow, and is usually connected with the last thoracic nerve by a small offset from that nerve, named *thoracico-lumbar*; below, it is wider, and is joined to the sacral plexus by means of a branch passing from the fourth lumbar nerve to the fifth.

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[1] Journ. Anat. xxvi. 1891. In 96 out of 112 specimens the last thoracic was the lowest nerve to supply the rectus abdominis (Bardeen, Amer. Journ. of Anatomy, vol. i. No. 2).

The nerves entering the lumbar plexus do not form an interlacement, as in the brachial plexus, but the several nerves of distribution proceeding from the plexus for the most part arise by two or more roots from a corresponding number of spinal nerves, so as to produce the appearance of a series of loops. The usual arrangement may be thus stated: The *first lumbar* nerve, having been joined by the branch from the last thoracic, gives off the ilio-hypogastric and ilio-inguinal nerves, and sends downwards a communicating branch to the second nerve. The fibres of the thoracico-lumbar cord enter chiefly the ilio-hypogastric nerve, but some may pass also to the ilio-inguinal. The descending branch of the first nerve contributes to the genito-femoral, often to the femoral, and occasionally to the obturator nerve. The *second lumbar* nerve furnishes the greater part of the genito-femoral and lateral cutaneous nerves, and gives a connecting branch to the third, from which some of the fibres of the femoral and obturator nerves are derived. From the *third* nerve three branches proceed: the largest part enters the femoral nerve; a small branch, dorsally placed, joins the lateral cutaneous; and the third, arising from the ventral

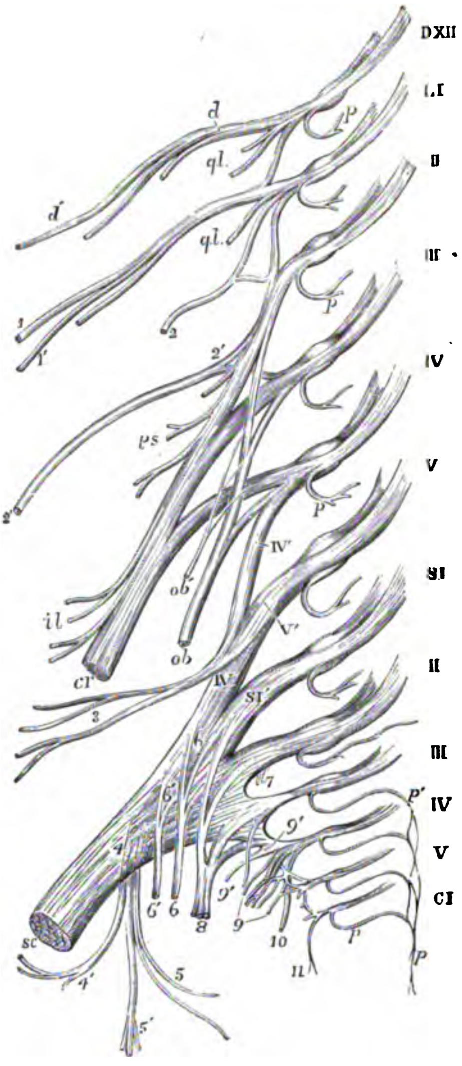


Fig. 56. — Diagram of the lumbar and sacral plexuses with the principal nerves arising from them. (Allen Thomson.) ⅓.

DXII, the divided roots of the last thoracic nerve; LI to V, the roots of the five lumbar nerves; the loops uniting the ventral primary divisions of these nerves together, and the first with the twelfth thoracic, are shown; SI to V, and CI, the sacral and coccygeal nerves; *p*, placed on some of the nerves, marks the dorsal primary divisions cut short; *p*, *p'*, the plexus formed by the union of the dorsal primary branches of the third, fourth, and fifth sacral and the coccygeal nerves; *d*, ventral division of the last thoracic nerve, from which *d'* the lateral cutaneous branch arises; 1, 1', ilio-hypogastric nerve, dividing into its two branches; the ilio-inguinal nerve is seen below these, without a number; 2, genito-femoral; 2', lateral cutaneous of the thigh; *q.l.*, branches to quadratus lumborum; *ps*, branches to the psoas muscle; *cr*, femoral nerve; *il*, branches to the iliacus; *ob*, obturator nerve; *ob'*, accessory obturator; IV', V', loop from the fourth and fifth lumbar, forming the lumbo-sacral cord; 3, superior gluteal nerve; *sc*, sciatic nerve, continued from the sacral plexus; 4, posterior cutaneous nerve arising from the plexus posteriorly; 4', inferior gluteal nerve; 5, inferior pudendal; 5', posterior cutaneous of the thigh and leg; 6, 6, branch to the obturator internus and gemellus superior; 6', 6', branch to the gemellus inferior, quadratus femoris, and hip-joint; 7, twigs to the pyriformis; 8, pudendal nerve; 9, visceral branches; 9', twig to the levator ani; 10, perforating cutaneous nerve; 11, coccygeal branches.

aspect of the trunk, passes to the obturator nerve. The *fourth* nerve also gives three branches, of which the anterior and posterior serve to complete the obturator and femoral nerves respectively, while the third, placed below the others, descends to join the *fifth* lumbar nerve, thus forming the *lumbosacral cord*, which enters into the sacral plexus.

The branches of the lumbar plexus form two sets, which are distributed, one to the lower part of the wall of the abdomen, the other to the fore-part and inner side of the lower limb. In the former set are the ilio-hypogastric, ilio-inguinal, and genito-femoral nerves, which, although mainly trunk-nerves, send cutaneous offsets to the thigh; and to the latter belong the lateral cutaneous, femoral, and obturator. The lateral cutaneous and femoral are dorsal branches of the plexus, and the obturator is a ventral branch.

Varieties of the lumbar plexus.—In the normal condition, the first three lumbar nerves enter wholly into the lumbar plexus, and the fifth lumbar nerve into the sacral plexus, while the fourth—the *nervus furcalis* of v. Jhering—is divided between the two plexuses. The proportion of the fourth nerve, which descends to the sacral plexus, is normally less than one-half, but it varies in different cases from one-twentieth to nine-tenths (Eisler). When the sacral division of this nerve is very large it may be joined by a branch from the third lumbar nerve; and conversely, when the sacral division of the fourth nerve is very small, the fifth lumbar nerve may send an offset to the lumbar plexus, where it contributes to the formation of the femoral and obturator nerves, or, perhaps, only to the former. In these cases there are therefore two furcal nerves—viz. 3 *l* and 4 *l*, or 4 *l* and 5 *l* respectively. Further, the sacral branch of the fourth lumbar nerve may be wanting, and then the fifth lumbar is the sole furcal nerve. A series may thus be traced in which the furcal nerves are progressively, from above downwards, 3 and 4 *l*, 4 *l*, 4 and 5 *l*, and 5 *l*. The lower limb is supplied by the lower nerves of the lumbar plexus and the upper nerves of the sacral plexus, these two sets of nerves forming the lumbo-sacral plexus. This plexus, like the brachial, is liable to vary in its attachment, its nerves of origin having a tendency to arise higher or lower.

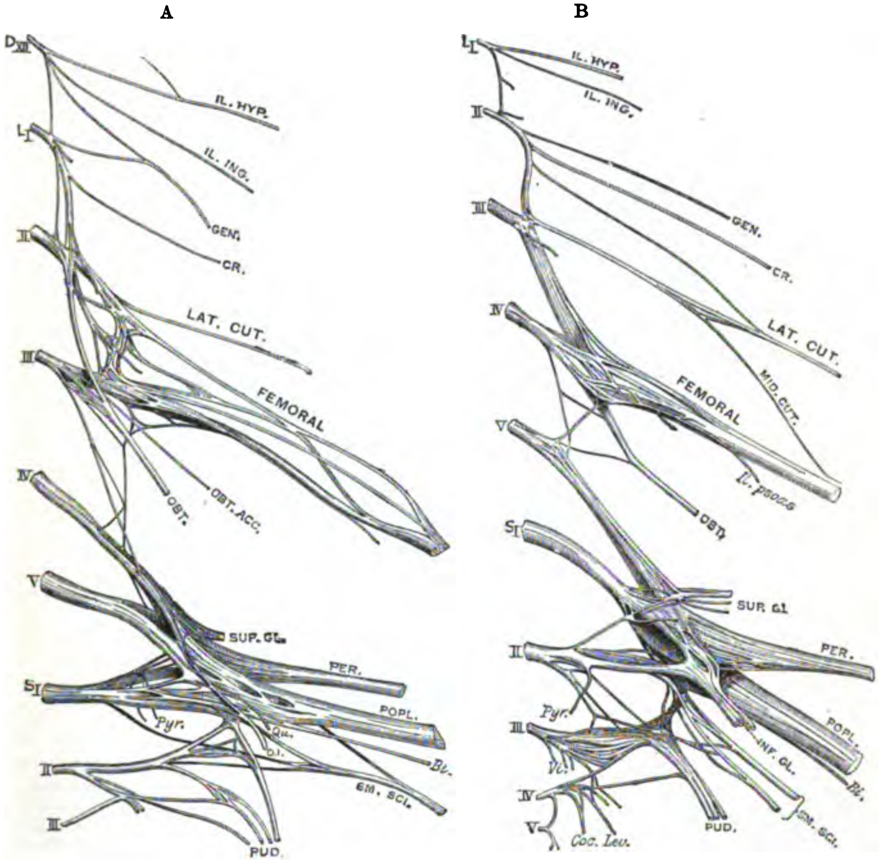
In the slighter degrees of variation this is shown by a difference in the size of the contributing roots, so that a given trunk will derive a larger share of its fibres from an upper, and a smaller share from a lower spinal nerve, or *vice versâ*; but in the more marked degrees the origin may be shifted upwards or downwards to the extent of one spinal nerve. There are thus to be distinguished two extreme forms of plexus (fig. 57), which may be called *high* and *low* (the 'anterior' and 'posterior' forms of Langley, 'prefixed' and 'postfixed' types of Sherrington), and between which the normal or average plexus is placed, as is shown, for the lumbar plexus only, in the following table, wherein the order of the nerves in each case indicates the size of the roots in descending series, and the roots enclosed in parentheses are inconstant:

	High form.	Normal form.	Low form.
Lateral cutaneous	2, (1) *l*	2, 3 *l*	3, 2*l*
Obturator	3, 2, 4, 1 *l* (very rarely 3, 2, 1 *l*)	3, 4, 2 *l*	4, 3, 5, 2 *l*
Femoral	3, 2, 4, 1 *l*, (12 *d*)	4, 3, 2, 1 *l*	4, 3, 5, 2 *l*
Furcal nerves	3 and 4 *l* (or 4 *l* with large sacral division)	4 *l*	4 and 5 *l*, or 5 *l*

Forms intermediate to these also occur; and the relations of the several offsets of the plexus to one another sometimes vary to a limited extent: that is, one nerve may have a high origin, while the others belong to the normal form, or *vice versâ*. Variations are more frequent and extensive in the downward direction than the opposite. In some instances the extreme forms are associated with irregularities of the vertebral column, the low form of plexus with an additional movable vertebra, and the high form with assimilation of the fifth lumbar vertebra to the sacrum, but this is not always the case. The upper three offsets of the lumbar plexus, not being true limb-nerves, do not vary so much in their origin, although they also are affected at times by the general form of the plexus; on the other hand, it may happen with a low form of plexus that the ilio-hypogastric and ilio-inguinal nerves receive an additional root from the twelfth thoracic (Paterson). Ancel and Sencert examined the lumbar plexus in sixty-four cases and found that in forty-seven it was formed by four spinal nerves, in fourteen by five,

and in three by six. The elongation of the plexus, which occurred in seventeen cases, was due to an additional spinal root above or below, or in both directions, and was not necessarily associated with a change in position of the *nervus furcalis*. These authors object to the terms 'prefixed' or 'postfixed' as applied to variations in the lumbar plexus.[1]

Ilio-hypogastric and ilio-inguinal nerves.—These nerves are the upper two branches of the lumbar plexus. They are both derived mainly from the first lumbar nerve, and have a nearly similar course and distribution, corresponding together to the ventral (intercostal) division of a thoracic nerve.


A
B
DXII
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Coc. Lev.

FIG. 57.—EXTREME FORMS OF LUMBAR AND SACRAL PLEXUSES. (From Eisler.)

A. High form of plexus: ventral aspect. From a subject in which the fifth lumbar vertebra was assimilated to the sacrum, and articulated on both sides with the ilium.

B. Low form of plexus: dorsal aspect. From a subject in which there were thirteen thoracic and five lumbar vertebræ.

They pass forwards between and through the broad muscles of the abdomen, furnish a lateral cutaneous branch to the integument of the hip, and, becoming subcutaneous anteriorly, end in the integument of the lowest part of the abdomen and scrotum in the male, or labium pudendi in the female, as well as the adjacent part of the thigh. The extent of distribution of the one is inversely proportional to that of the other.

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[1] **See on this subject: J. N. Langley (lumbar plexus of cat), Journ. Phys. xii. 349, xv. 210, and xvii. 296; C. S. Sherrington (cat and monkey), Journ. Phys. xiii. 639; P. Eisler, Der Plexus lumbosacralis des Menschen, Halle, 1892; A. M. Paterson, Journ. Anat. xxviii. 84; C. R. Bardeen and A. W. Elting, Anat. Anzeiger, xix.; P. Ancel and L. Sencert, Bibliographie anatomique, ix. 1901.**

The **ilio-hypogastric nerve,** the highest and largest of the branches proceeding from the first lumbar nerve, usually receives fibres also from the last thoracic nerve through the thoracico-lumbar cord. Issuing from the upper part of the psoas muscle at the outer border, it runs obliquely over the quadratus lumborum to the iliac crest, and, there perforating the transverse muscle of the abdomen, gets between that muscle and the internal oblique, and divides into an iliac and a hypogastric branch.

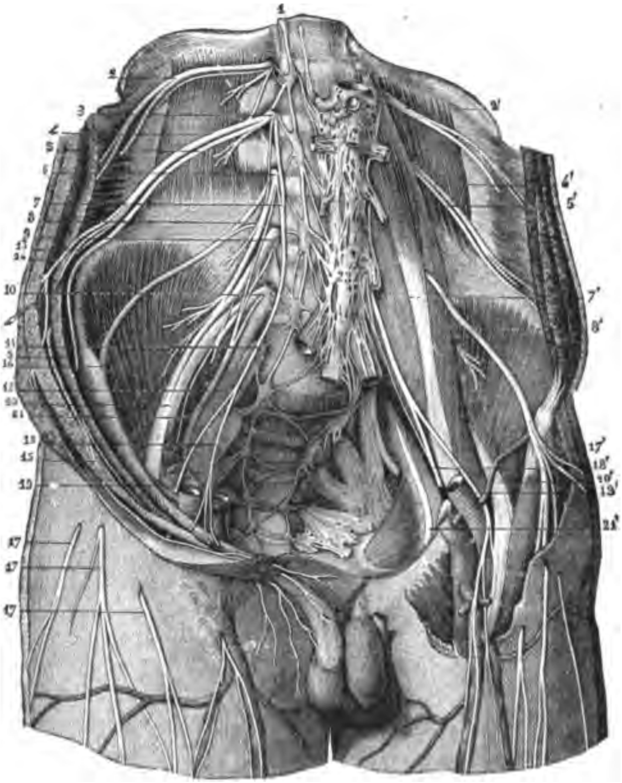

FIG. 58.—VIEW FROM BEFORE OF THE VENTRAL PRIMARY BRANCHES OF THE LUMBAR AND SACRAL NERVES WITH THE PLEXUSES. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{4}$.

1, lumbar part of the sympathetic cord; 2, 2', ventral primary division of the twelfth thoracic nerve; 3. first lumbar; 4, 4', ilio-hypogastric branch of this nerve; 5, 5', ilio-inguinal branch; 6, second lumbar nerve; 7, 7', genito-femoral nerve; 8, 8', lateral cutaneous nerve of the thigh; 9, third lumbar nerve; 10, fourth; 11, fifth; 12, lumbo-sacral cord; 13, iliac branch of the ilio-hypogastric; 14, its abdominal branch; 15, ilio-inguinal nerve; 16, lateral cutaneous nerve of the right side passing out of the abdomen under Poupart's ligament; 17, 17, 17, cutaneous ramifications of this nerve; 17', the same nerve exposed on the left side; 18, 18', genital branch of the genito-femoral; 19, 19, its femoral branch on the right side; 19', the same on the left side exposed as it descends in front of the femoral artery; 20, 20 , femoral nerve; 21, 21', obturator nerve; 22, left sacral plexus; 23, aortic plexus of the sympathetic, connected with the other pre-aortic plexuses and the lumbar ganglia.

The *iliac branch* (*ramus cutaneus lateralis*) pierces the internal oblique muscle, and then emerges through the external oblique close to the iliac crest about the junction of its middle and anterior thirds, to be distributed to the integument over the gluteus medius and tensor fasciæ latæ muscles.

The *hypogastric* or *abdominal branch* passes on between the transversalis and internal oblique muscles, to both of which it supplies twigs, and is connected with the ilio-inguinal nerve near the iliac crest. It then perforates the internal oblique muscle, and, piercing the aponeurosis of the external oblique a little above the external abdominal ring, is distributed to the skin of the abdomen above the pubis (*ramus cutaneus anterior*).

Varieties.—The ilio-hypogastric nerve is occasionally derived from the last thoracic, and it may even receive a root from the eleventh thoracic nerve (fig. 57, A). The iliac branch varies in size inversely with the lateral cutaneous of the twelfth thoracic, and it is sometimes altogether wanting. The hypogastric branch is not unfrequently joined with the last thoracic nerve between the muscles. In some cases this branch supplies the pyramidalis muscle.

The **ilio-inguinal nerve,** smaller than the preceding, is also derived from the first lumbar nerve, and sometimes receives an accession from the thoracico-lumbar cord. Appearing from beneath the outer border of the psoas muscle below the ilio-hypogastric nerve, it is directed obliquely downwards and outwards over the quadratus lumborum and iliacus to the fore-part of the iliac crest, where it perforates the transversalis and comes into communication with the ilio-hypogastric nerve. Then, piercing the internal oblique muscle, it descends in the inguinal canal, and, emerging at the external abdominal ring on the outer side of the spermatic cord, divides into branches which are distributed to the skin of the pubic region and root of the penis and scrotum in the male, or labium pudendi in the female (*nn. scrotales s. labiales anteriores*), and of the adjacent upper and inner part of the thigh. In its progress this nerve may furnish branches to the internal oblique and transversalis muscles.

Varieties.—The ilio-hypogastric and ilio-inguinal nerves often arise by a common trunk, which divides after perforating the transversalis muscle. The ilio-inguinal nerve is occasionally derived from the last thoracic nerve (fig. 57, A). On the other hand, it may spring from the loop between the first and second lumbar nerves, or even entirely from the latter nerve. It is sometimes small, and ends near the iliac crest by joining the ilio-hypogastric nerve, which in that case gives off an inguinal branch having a similar course and distribution to the ilio-inguinal nerve. The ilio-inguinal nerve may be absent, its place being taken by the genital, rarely by the femoral branch of the genito-femoral. In some cases the nerve has an iliac or lateral branch, which is distributed to the skin in the neighbourhood of the anterior superior iliac spine. The ilio-inguinal nerve may also replace to a greater or less extent the genital branch of the genito-femoral or (very rarely) the lateral cutaneous nerve (M. Griffin).

Genito-femoral (genito-crural) nerve.—This nerve belongs partly to the external genital organs and partly to the thigh. It is derived chiefly from the second lumbar nerve, but receives also a few fibres from the connecting cord between that and the first nerve. The nerve descends obliquely through the psoas muscle, from which it emerges near the inner border, about on a level with the disc between the third and fourth lumbar vertebræ, and then lying on the fascia covering the anterior surface of that muscle divides at a variable height into an internal or genital, and an external or femoral branch. It often bifurcates close to its origin from the plexus, in which case its two branches perforate the psoas muscle in different places.

The *external genital* (*spermatic*) *branch* lies upon or near the external iliac artery, and sends a filament along that vessel; then perforating the transversalis fascia (or passing through the deep abdominal ring) it traverses the inguinal canal with the spermatic cord, supplies the cremaster muscle, and sends filaments to the skin of the scrotum and adjoining corner of the thigh. In the female it accompanies the round ligament of the uterus to the skin of the groin.

The *femoral* (*crural*) *branch* descends upon the psoas muscle beneath Poupart's ligament into the thigh. Immediately below that ligament, and at the outer side of the femoral artery, it pierces the fascia lata, and supplies the skin on the upper part of the thigh, communicating with the anterior cutaneous branch of the femoral nerve. While it is passing beneath Poupart's ligament, some filaments are prolonged from this nerve on the femoral artery.

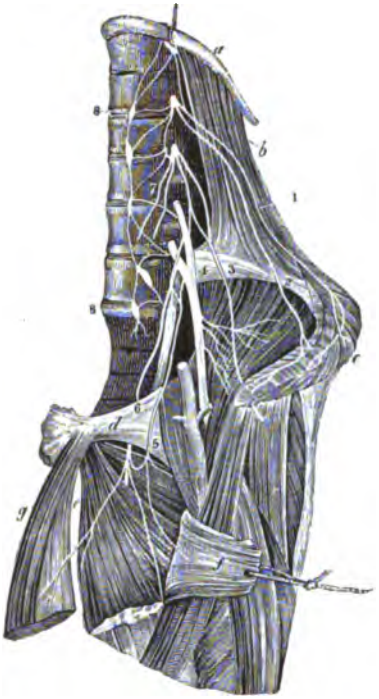

FIG. 59. — THE LUMBAR PLEXUS FROM BEFORE, WITH THE DISTRIBUTION OF SOME OF ITS NERVES. (Slightly altered from Schmidt.) ⅛.

a, last rib; *b*, quadratus lumborum muscle; *c*, oblique and transverse muscles, cut near the crest of the ilium and turned down; *d*, pubis; *e*, adductor brevis muscle; *f*, pectineus divided and turned outwards; *g*, adductor longus; 1, ilio-hypogastric nerve; 2, ilio-inguinal; 3, lateral cutaneous; 4, femoral; 5, accessory obturator; 6, obturator, united with the accessory by a loop round the pubis; 7, genito-femoral in two branches cut short near their origin; 8, 8, lumbar portion of the gangliated sympathetic cord.

Varieties.—This is the most variable branch of the lumbar plexus. The two divisions of the genito-femoral nerve often arise independently from the lumbar plexus (fig. 57, A and B). The genital branch is occasionally derived from the last thoracic and first lumbar nerves (fig. 57, A). Either branch may proceed wholly from the first or the second lumbar nerve (fig. 57, B). Absence of either division, or more rarely of the whole nerve, may occur: in such cases the fibres usually forming the genital branch are associated with the ilio-inguinal nerve, and those belonging to the femoral division with the lateral cutaneous or femoral nerve. Conversely, the genital branch may reinforce or replace the ilio-inguinal nerve, and the femoral branch the lateral or middle cutaneous. The genital branch often gives filaments to the lower fibres of the internal oblique and transversalis muscles.

Lateral cutaneous nerve (*external cutaneous*).—This nerve, arising from the second and third lumbar nerves, emerges from the outer border of the psoas muscle and crosses the iliacus below the ilio-inguinal nerve, where it is placed beneath the iliac fascia. It passes under Poupart's ligament, and enters the thigh immediately below the anterior superior iliac spine, where it divides into an anterior and a posterior branch distributed to the integument of the outer side of the hip and thigh (fig. 60, 1).

The *posterior branch* perforates the fascia lata and subdivides into two or three others, which turn backwards and supply the skin upon the outer surface of the limb, from the great trochanter nearly to the middle of the thigh. The highest among them are crossed by the cutaneous branches from the last thoracic nerve.

The *anterior branch*, the continuation of the nerve, is at first contained in a canal formed in the substance of the fascia lata; but about four inches below Poupart's ligament it enters the subcutaneous fatty tissue, and is distributed along the outer part of the front of the thigh, ending near the knee. The principal offsets spring from its outer side. In some cases, this branch reaches quite down to the knee, and takes part there in the formation of the patellar plexus.

Varieties.—In the normal form of lumbar plexus the lateral cutaneous nerve is derived mainly from the second lumbar nerve, and receives only a small root from the third. In the high form of plexus it arises entirely from the second lumbar nerve, or from the second and first; while in the low form its chief root is furnished by the third nerve. The lateral cutaneous nerve often accompanies, or is united with, the femoral trunk to below Poupart's ligament. The posterior branch is sometimes replaced by an offset of the genito-femoral nerve. In one instance the place of the lateral cutaneous nerve was taken by a branch of the ilio-inguinal (M. Griffin).

Obturator nerve.—The obturator nerve arises from the lumbar plexus generally by three roots, which proceed from the second, third, and fourth lumbar nerves, and of which that from the third is the largest, while the root from the second nerve is often very small. Having emerged from the inner border of the psoas muscle, opposite to the brim of the pelvis, it runs along the side of the pelvic cavity, above the obturator vessels, as far as the opening in the upper part of the thyroid foramen, through which it escapes from the pelvis into the thigh. In the foramen, it divides into an anterior and a posterior branch, which are separated from one another by some fibres of the obturator externus, and lower down by the short adductor muscle.

A. The *anterior* or *superficial portion* communicates with the accessory obturator nerve, when this is present, and descends over the upper border of the obturator externus and in front of the adductor brevis, but behind the pectineus and adductor longus muscles. It gives branches as follows:

An *articular branch* to the hip-joint arises in the thyroid foramen.

Muscular branches are given to the gracilis and adductor longus muscles, and generally also to the adductor brevis.

The *terminal twig* turns outwards upon the femoral artery, and surrounds that vessel with small filaments.

An offset at the lower border of the adductor longus communicates beneath the sartorius with one of the anterior cutaneous branches of the femoral nerve, and with a branch of the saphenous nerve, forming a sort of plexus.

B. The *posterior* or *deep part* of the obturator nerve, having perforated the upper fibres of the obturator externus muscle, crosses behind the short adductor to the fore-part of the adductor magnus, where it divides into several branches, all of which end in those muscles, excepting one which is prolonged downwards to the knee-joint.

The *muscular branches* supply the external obturator and the great adductor muscle, with the short adductor also when this muscle receives no branch from the anterior division of the nerve.

The *articular branch* for the knee rests at first on the adductor magnus, but perforates the lower fibres of that muscle, and thus reaches the upper part of the popliteal space. Supported by the popliteal artery, and sending filaments around that vessel, the nerve then descends to the back of the knee-joint, and enters the articulation through the posterior ligament. This branch is often wanting.

Varieties.—The obturator nerve sometimes has an additional root from the first or the fifth lumbar nerve. In extreme cases of the high form of the plexus it may arise from the upper three lumbar nerves. The root from the second nerve is rarely wanting (Eisler). It occasionally gives a branch to the pectineus muscle. A branch to the obturator internus is described by Krause. Eisler traced filaments to the obturator artery and the periosteum on the back of the pubis.

Occasional cutaneous nerve.—In some instances the communicating branch from the anterior division of the obturator nerve to the internal branch of the anterior cutaneous is larger than usual, and descends along the posterior border of the sartorius to the inner side of the knee, where it perforates the fascia, communicates with the saphenous nerve, and extends down the inner side of the limb, supplying the skin as low as the middle of the leg.

When this cutaneous branch of the obturator nerve is present, the internal cutaneous branch of the femoral nerve is small, the size of the two nerves bearing an inverse proportion to each other.

Accessory obturator nerve.—This slender nerve is present in one out of every three or four bodies (29 per cent., Eisler). It arises from the third and fourth lumbar nerves (rarely also from the fifth, sometimes only from the third), between the roots of the obturator and femoral nerves, being associated at its origin more closely with the latter, but it is often bound up for a short distance with the obturator nerve, of which it then appears to be a branch. It descends beneath the iliac fascia along the inner border of the psoas muscle, crosses over the superior ramus of the pubis, and, passing behind the pectineus muscle, ends by dividing into branches. Of these, one joins the superficial part of the obturator nerve; another enters the pectineus on its under-surface; and a third passes to the hip-joint. Through the communication with the obturator nerve fibres may also pass to the adductor longus, gracilis, and adductor brevis muscles, rarely to the skin of the inner side of the thigh. The accessory nerve is sometimes very small, and ends in filaments which perforate the capsule of the joint.[1]

SUMMARY.—The obturator nerve and accessory obturator supply the three adductor muscles of the thigh, with the gracilis and obturator externus, and in some cases the pectineus. They also give branches to the hip and knee-joints; and occasionally a cutaneous branch descends to the inner side of the thigh, and to the inner and upper part of the leg.

Femoral nerve (*anterior crural*).—This, the largest nerve arising from the lumbar plexus, is derived principally from the third and fourth lumbar nerves, but in part also from the second and first. Emerging from the outer border of the psoas muscle near its lower part, it descends into the thigh in the groove between that muscle and the iliacus, and therefore to the outer side of the femoral blood-vessels. Just below Poupart's ligament, the nerve becomes flattened out and divides into two parts, one of which is mainly cutaneous, while the other is distributed for the most part to muscles.

Branches in the trunk.—The branches given from the femoral nerve within the abdomen are few and of small size.

The *iliacus* receives three or four small branches (2, 3 *l*), which are directed outwards from the nerve to the muscle.

The *nerve of the femoral artery* is a small branch which divides into numerous filaments upon the upper part of that vessel. It sometimes arises lower down than usual, in the thigh. It may, on the other hand, be found to take origin above the ordinary position, from the third lumbar nerve. Beck and Rauber describe a filament passing from this nerve, in company with the medullary artery, to the femur.

Terminal branches.—From the principal or terminal divisions of the nerve the remaining branches take their rise as follows:

From the *superficial* or *anterior division* cutaneous branches are given to the fore-part and to the inner side of the thigh and knee; they are the anterior cutaneous nerves. Two muscles, the sartorius and the pectineus, receive their nerves from this group.

Rami cutanei anteriores.—These branches supply twigs to the front and inner side of the thigh, and are usually described as the middle and the internal cutaneous nerves.

Middle cutaneous nerve. — The middle cutaneous nerve (2, 3 *l*) either pierces the fascia lata in two parts about four inches below Poupart's ligament, or as one trunk which soon divides into two branches. These branches descend on the fore-part of the thigh to the front and inner side of the patella. After or before the nerve has become subcutaneous, it communicates with the femoral branch of the genito-femoral nerve, and also with the internal cutaneous.

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[1] See A. M. Paterson, 'The Pectineus Muscle and its Nerve-supply,' Journ. Anat. xxvi. 1891; and *op. cit. s.*, Journ. Anat. xxviii. 95; P. Eisler, Der Plexus lumbosacralis, 1892.

This nerve, or the outermost of its branches, frequently pierces the upper part of the sartorius muscle.

Internal cutaneous nerve. — The internal cutaneous nerve (2, 3 *l*) gives branches to the skin on the inner side of the thigh, and the upper part of the leg; but the extent to which it reaches varies with the presence or absence of the 'occasional cutaneous' branch of the obturator nerve.

Lying beneath the fascia lata, this nerve descends obliquely over the upper part of the femoral artery. It divides either in front of that vessel, or at the inner side, into two branches (one anterior, the other posterior), which pierce the fascia separately. Before dividing, this nerve gives off two or three cutaneous twigs, which accompany the upper part of the long saphenous vein. The highest of these perforates the fascia near the saphenous opening, and reaches down to the middle of the thigh. Another, larger than the rest, passes through the fascia about the middle of the thigh, and extends to the knee. In some instances, these small branches spring directly from the femoral nerve; and one branch is frequently given off from the nerve to the pectineus, joining in a loop on the inner side of the femoral artery with a branch passing in front of that vessel (fig. 60, 8; fig. 61, 7).

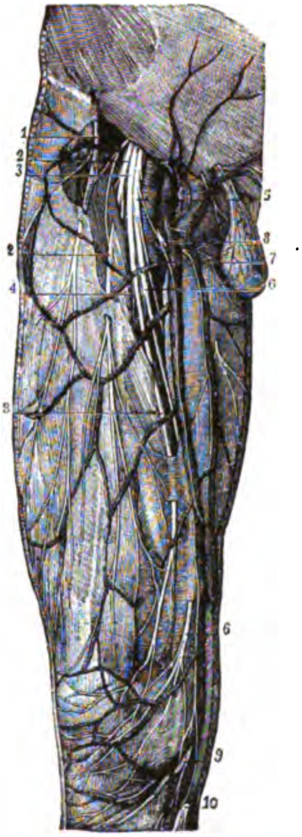

FIG. 60.—CUTANEOUS NERVES OF THE ANTERIOR AND INNER PART OF THE THIGH. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{5}$.

1, lateral cutaneous nerve; 2, 3, middle cutaneous, the outer one passing through the sartorius muscle; 4, filament to the sartorius; 5, internal cutaneous nerve; 6, its anterior division; 7, one of its upper branches; 8, a cutaneous twig from the nerve to the pectineus; 9, patellar branch of the saphenous nerve; 10, continuation of the saphenous to the leg.

The *anterior branch*, descending in a straight line to the knee, perforates the fascia lata in the lower part of the thigh; it afterwards runs down near the tendon of the adductor magnus, giving off filaments on each side to the skin, and is finally directed over the patella to the outer side of the knee. It communicates above the joint with a branch of the saphenous nerve; and sometimes it takes the place of the branch usually given by the latter to the integument over the patella.

The *posterior branch* of the internal cutaneous nerve, descending along the posterior border of the sartorius muscle, perforates the fascia lata at the inner side of the knee, and communicates by a small branch with the saphenous nerve, which here descends in front of it. It gives some cutaneous filaments to the lower part of the thigh on the inner side, and is distributed to the skin upon the inner side of the calf. While beneath the fascia, this branch of the internal cutaneous nerve joins in an interlacement with offsets of the obturator and saphenous nerves below the middle of the thigh; and in the leg it communicates again with branches of the saphenous nerve.

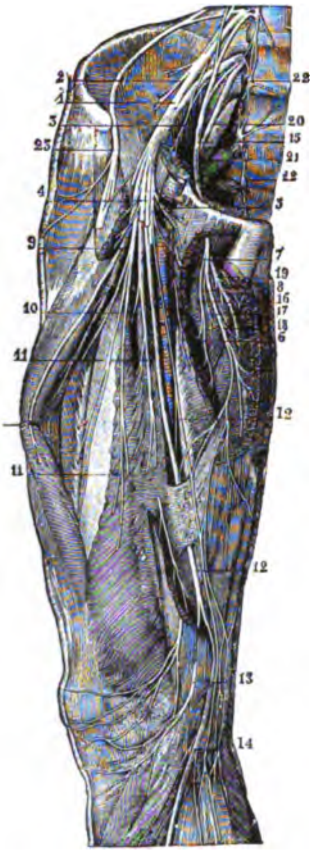

FIG. 61. — DEEP NERVES OF THE ANTERIOR AND INNER PART OF THE THIGH. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{5}$.

1, femoral nerve; 2, branches to the iliacus muscle; 3, branch to the lower part of the psoas; 4, internal and middle cutaneous nerves, divided to show the deeper branches; 5, 6, nerves to the pectineus; 7, cutaneous filament from the last; 8, posterior branch of the internal cutaneous nerve; 9, branch to the rectus; 10, branch to the vastus lateralis; 11, branch to the vastus mesialis; 12, saphenous nerve; 13, its patellar branch; 14, its continuation to the leg; 15, obturator nerve; 16, branch to the adductor longus; 17, branch to the adductor brevis; 18, branch to the gracilis: from this a filament is prolonged downwards, to unite with the plexus formed by the union of branches from the internal cutaneous and saphenous nerves; 19, deep branch of the obturator nerve to the adductor magnus; 20, lumbo-sacral cord; 21, its union with the first sacral nerve; 22, 22, lumbar and sacral parts of the sympathetic nerve; 23, lateral cutaneous nerve.

The *branch to the pectineus* (2, 3 *l*) is usually associated at its origin with the internal cutaneous nerve. It crosses inwards behind the femoral vessels, and enters the muscle on its anterior aspect: this branch is occasionally double.

The *sartorius* muscle receives two or three twigs (2, 3 *l*) which arise in common with the middle cutaneous nerve, and enter the upper part of the muscle.

From the *deep* or *posterior division* branches proceed to supply the extensor muscle of the knee, and also one cutaneous nerve, the saphenous.

The *branch to the rectus femoris* (3, 4 *l*) enters the posterior surface of its muscle: from this nerve, and from some of the other muscular branches, twigs are sent, in company with a branch of the external circumflex artery, to the hip-joint.

The *nerve to the vastus lateralis* (3, 4 *l*), of considerable size, descends with a large branch of the external circumflex artery along the anterior border of the muscle, and sends a filament to the knee-joint.

Two or three branches (3, 4 *l*) penetrate the *vastus intermedius* (crureus) muscle on its anterior surface, and from the most internal of these a filament can be traced, under cover of the anterior border of the vastus mesialis muscle, to the *subcrureus*, the periosteum of the lower end of the femur, and the synovial membrane of the knee-joint.

The *nerve of the vastus mesialis* (3, 4 *l*) runs downwards with the saphenous nerve beneath the aponeurosis covering the femoral vessels, giving several branches to the upper part of its muscle; it enters the latter about the middle of the thigh, and from its lower end a considerable twig is continued to the knee-joint, in company with the deep branch of the anastomotic artery.

The *saphenous nerve* (the internal or long saphenous, 3, 4 *l*) is the largest of the branches of the femoral nerve. It is deeply placed as far as the knee, but is subcutaneous in the rest of its extent.

In the thigh, it accompanies the femoral vessels, lying at first to their outer side, but lower down gradually crossing over the artery, and passing through Hunter's canal beneath the same aponeurosis. When the vessels pass through the opening in the adductor magnus muscle into the popliteal space, the saphenous nerve separates from them, and is continued beneath the sartorius muscle to the inner side of the knee; here, having first given off, as it lies near the inner condyle of the femur, a branch which is distributed over the front of the patella, it becomes subcutaneous by piercing the fascia at the lower border of the sartorius.

The nerve then accompanies the saphenous vein along the inner side of the leg, and, passing in front of the inner ankle, terminates on the inner side of the metatarsal region of the foot. In the leg it is connected with the posterior branch of the internal cutaneous nerve.

The distribution of its branches is as follows:

A *communicating branch* is given off about the middle of the thigh to join in the interlacement formed beneath the sartorius by this nerve and branches of the obturator and internal cutaneous nerves.

The *patellar branch* perforates the sartorius muscle and the fascia lata, and spreads out over the front of the knee, where it forms, by uniting with branches of the internal and middle (sometimes also the lateral) cutaneous nerves, a plexus named the *patellar plexus*.

Numerous branches are given off from the nerve to the skin of the leg, and the larger of these turn forwards over the anterior border of the tibia. Its terminal offsets on the inner side of the foot communicate with branches of the musculo-cutaneous nerve.

Varieties.—In the high form of plexus the femoral may receive fibres from the last thoracic nerve, in the low form from the fifth lumbar, the root at the opposite end of the plexus being correspondingly reduced. The nerve has been seen entering the thigh between the femoral artery and vein (Dubrueil). The several branches of the middle, or of the internal, cutaneous nerve frequently arise independently from the femoral. The middle or internal cutaneous nerve sometimes leaves the trunk of the femoral at a higher level than usual, within the abdomen. The posterior branch of the internal cutaneous is sometimes very small or absent, its place being supplied by the obturator or the saphenous nerve. The femoral occasionally gives off the lateral cutaneous nerve of the thigh. The saphenous nerve has been seen ending at the knee, its place in the leg being taken by a branch of the tibial nerve (G. H. Meyer). The patellar branch has been observed arising from the nerve to the vastus mesialis.[1] In rare instances the saphenous furnishes the internal dorsal digital nerve of the great toe. Branches of the femoral nerve to the tensor fasciæ latæ and adductor longus are described by several anatomists. Arthur Thomson found a branch passing behind the femoral vessels to join the accessory obturator nerve and supply in part the latter muscle.[2]

SUMMARY.—The femoral nerve is distributed to the skin upon the fore-part and inner side of the thigh, commencing below the termination of the ilio-inguinal and genito-femoral nerves. It furnishes also a cutaneous nerve to the inner side of the leg and foot. All the muscles on the front of the thigh receive their nerves from the femoral, and the iliacus and pectineus are also supplied by this nerve. Lastly, branches are given from the femoral nerve to the femoral artery, to the thigh-bone, and to the hip and knee joints.

Fifth lumbar nerve.—The ventral primary division of the fifth lumbar nerve, having received a fasciculus from the nerve next above it, descends to join the first sacral nerve, and forms part of the sacral plexus. The trunk resulting from the union of the fifth with a part of the fourth nerve is named the *lumbo-sacral cord*, and gives origin to the greater part of the superior gluteal nerve.

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[1] Guy's Hosp. Reports (3rd ser.), xvi. 161.

[2] Journ. Anat. xix. 331.

SACRAL AND COCCYGEAL NERVES.

The ventral primary divisions of the first four sacral nerves emerge from the spinal canal by the anterior sacral foramina, and the fifth passes forwards between the sacrum and coccyx.

The first two sacral nerves are large, and of nearly equal size; the others diminish rapidly, and the fifth is exceedingly slender. Like the ventral divisions of the other spinal nerves, those of the sacral nerves communicate with the sympathetic; the communicating cords are very short, as the sympathetic ganglia are close to the inner margin of the foramina of the sacrum.

The first three nerves and part of the fourth contribute to form the sacral plexus. The fifth has no share in the plexus—it ends on the back of the coccyx. As the description of the fourth and fifth sacral nerves and of the coccygeal will occupy only a short space, these three nerves may be noticed first, before the other nerves and the numerous branches to which they give rise are described.

Fourth sacral nerve.—Only one part of the ventral division of this nerve joins the sacral plexus; the remainder, which is more than half the nerve, supplies branches to the viscera and muscles of the pelvis, and sends downwards a connecting filament to the fifth nerve.

The *visceral branches* of the fourth sacral nerve are directed forwards to the lower part of the bladder, and communicate freely with branches from the sympathetic nerve. Offsets are distributed to the neighbouring viscera, according to the sex (*nervi hæmorrhoidales medii; nervi vesicales inferiores; nervi vaginales*). They will be described with the pelvic portion of the sympathetic nerve. These branches are associated with others proceeding from the third sacral nerve, and they are sometimes derived mainly from the latter nerve. Sometimes filaments are added from the second sacral nerve.

Of the *muscular branches*, one supplies the *levator ani*, piercing that muscle on its pelvic surface; another enters the *coccygeus*; while a third (*hæmorrhoidal* or *perineal branch*) ends in the *external sphincter* muscle of the anus. The last branch, after passing either through the coccygeus or between it and the levator ani, reaches the perineum, and gives filaments also to the integument between the anus and the coccyx.

Max Weiller[1] found that out of thirty subjects examined the levator ani was supplied by the third sacral nerve in seventeen and by the fourth sacral in thirteen.

Fifth sacral nerve.—The ventral branch of this, the lowest sacral nerve, comes forwards through the coccygeus muscle opposite the junction of the sacrum with the first coccygeal vertebra; it then descends upon the coccygeus nearly to the tip of the coccyx, where it turns backwards through the fibres of the coccygeus, and ends in the integument upon the posterior and lateral aspect of the bone (*nervi ano-coccygei*).

As soon as this nerve appears in front of the coccygeus muscle (in the pelvis) it is joined by the descending filament from the fourth nerve, and lower down by the small ventral division of the coccygeal nerve. It supplies filaments to the coccygeus muscle.

Coccygeal nerve.—The ventral branch of the coccygeal, or, as it is sometimes named, the sixth sacral nerve, is a very small filament. It escapes from the spinal canal by the terminal opening, pierces the sacro-sciatic ligaments and the coccygeus muscle, and, being joined upon the side of the coccyx with the fifth sacral nerve, partakes in the distribution of that nerve. The connexion between the fourth and fifth sacral and the coccygeal nerves is sometimes described as the *coccygeal plexus.*

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[1] 'Die Innervation des Musculus levator ani,' Anat. Anzeiger, xxvii

Sacral plexus.—The lumbo-sacral cord (resulting, as before described, from the junction of the fifth and part of the fourth lumbar nerves), the ventral primary divisions of the first three sacral nerves, and part of the fourth, unite to form this plexus. Its construction is simpler than that of the spinal nerve-plexuses already described, as the several nerves unite without much interlacement into an upper large, and a lower small, cord or band. The upper band is formed by the union of the lumbo-sacral cord with the first and second, and the greater part of the third, sacral nerves, and is continued into the sciatic nerve: the lower band, which has a more plexiform arrangement, results mainly from the junction of the smaller part of the third sacral nerve with the portion of the fourth nerve belonging to the plexus, and is prolonged into the pudendal nerve. The lower band is, however, joined by a small fasciculus from the second sacral nerve, and according to Eisler it receives fibres also from the first sacral nerve. To the place of union the nerves proceed in different directions, that of the upper being obliquely downwards, while that of the lower is nearly horizontal; and, as a consequence of this difference, they diminish in length from the first to the last. The sacral plexus rests on the anterior surface of the sacrum and of the pyriformis muscle, and, escaping through the great sacro-sciatic foramen, ends at the lower border of the pyriformis in the sciatic and pudendal nerves.

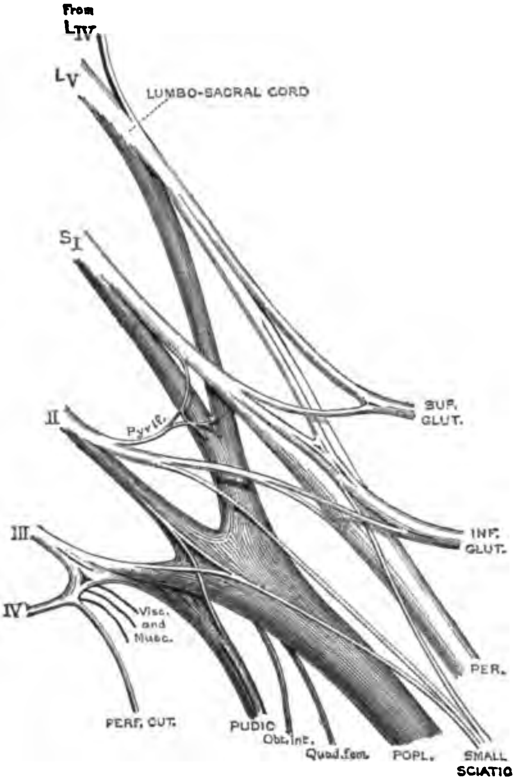

Fig. 62.—The sacral plexus of the right side. From behind. (G. D. Thane.)

The peroneal and tibial divisions of the sciatic nerve are separated up to their origin. The dorsal offsets of the plexus are repersented light, and the ventral offsets dark.

In addition to the terminal offsets—viz. the sciatic and pudendal nerves—the sacral plexus gives origin to a number of collateral branches of smaller size. These are the superior gluteal, inferior gluteal, posterior cutaneous of the thigh, and perforating cutaneous nerves, and branches to the pyriformis, obturator internus, gemelli, and quadratus femoris muscles.

In the description of the sacral plexus a division is sometimes made into two subordinate plexuses. The larger upper part, which ends in the sciatic nerve and gives off the other branches to the limb, is distinguished as the *plexus ischiadicus* (*sciatic plexus*), while the smaller lower part, including the pudendal nerve together with the visceral and muscular branches of the third and fourth sacral nerves, is designated the *plexus pudendus* (*pudic plexus*).

In the usual condition the greater part of the sacral plexus is prolonged, as already stated, into the sciatic trunk, which divides at a variable level in the thigh into the tibial and peroneal nerves. But in many cases (one in five or six) these nerves spring independently from the plexus, and the peroneal division passes backwards through a cleft in the pyriformis muscle, the lower part of which is interposed between the two nerves. In the normal arrangement also the two nerves can be readily separated up to the pelvis by dissecting off the sheath of the sciatic trunk, and it is then found that the plexus and the nerves entering it are divided into ventral and dorsal portions, the tibial nerve being formed by the union of the ventral divisions of the lumbo-sacral cord and the first three sacral nerves, while the peroneal receives the dorsal divisions of the lumbo-sacral cord and the first two sacral nerves. The collateral branches of the plexus may also be divided in a corresponding manner according as they arise from the ventral or dorsal divisions of the nerves, and thus the offsets of the plexus passing to the limb may be grouped as follows:

Ventral or anterior branches.	*Dorsal or posterior branches.*
Nerve to quadratus femoris.	Superior gluteal.
Nerve to obturator internus.	Inferior gluteal.
Tibial.	Nerves to pyriformis.
Posterior cutaneous (perineal branch and inner part of femoral division).	Peroneal.
	Posterior cutaneous (gluteal branches and outer part of femoral division).
	Perforating cutaneous.

Varieties of the sacral plexus.—The nerves proceeding from the sacral plexus vary in their origin, like the offsets of the lumbar plexus, in accordance with the position of the *nervus furcalis* (see p. 92). The range of variation is shown in the following table, mainly after Eisler:

	High form of plexus.	Normal form.	Low form.
Furcal nerves . . .	3 *l* and 4 *l* (or 4 *l* with large sacral division)	4 *l*	4 *l* and 5 *l*, or 5 *l*
N. to quad. fem. . .	4, 5 *l*	4, 5 *l*, 1 *s*	1 *s*, 5 *l*
N. to obt. int. . . .	1 *s*, 5, 4 *l*, 2 *s*	5 *l*, 1, 2 *s*	2, 1, 3 *s*
Tibial	1 *s*, 5, 4 *l*, 2 *s*, (3 *l*)	1 *s*, 5 *l*, 2 *s*, 4 *l*, 3 *s*	2, 1 *s*, 5 *l*, 3 *s*, (4 *s*)
Superior gluteal. . .	5, 4 *l*, 1 *s*	5 *l*, 1 *s*, 4 *l*, (2 *s*)	5 *l*, 1, 2 *s*
Inferior gluteal . . .	5 *l*, 1 *s*, 4 *l*	1 *s*, 5 *l*, 2 *s*	1, 2 *s*, 5 *l*
N. to pyriformis . .	(5 *l*), 1, 2 *s*	1, 2 *s*	2, 1, (3) *s*
Peroneal	5, 4 *l*, 1 *s*, (3 *l*)	5 *l*, 1 *s*, 4 *l*, 2 *s*	1, 2 *s*, 5 *l*, (3 *s*)
Posterior cutaneous . .	1, 2 *s*, 5 *l*	2, 3, 1 *s*	2, 3, 4 *s*
Pudendal	2, 3, 1 *s*, 5 *l*	3, 4, 2, 1 *s*	3, 4, 2, 1 *s*

(The relative size of the several roots is indicated by the order of the nerves, and those roots included in parentheses are inconstant.)

COLLATERAL BRANCHES.—**Small muscular branches.**—The *pyriformis muscle* is supplied by twigs arising from the back of the first and second sacral nerves.

The *nerve of the quadratus femoris muscle* arises from the front of the upper part of the plexus, receiving its fibres from the lumbo-sacral cord and first sacral nerve. Concealed at first by the sciatic nerve, it passes beneath the gemelli and the tendon of the obturator internus—between those muscles and the capsule of the hip-joint—and reaches the deep (anterior) surface of the quadratus. It gives off a branch to the inferior gemellus muscle, and another to the back part of the hip-joint. A second filament frequently passes directly from the sacral plexus to the articulation.

The *nerve of the obturator internus muscle,* derived from the fifth lumbar and upper two sacral nerves, springs from the front of the plexus immediately below the foregoing, with which it is usually connected at its origin. Appearing at the lower border of the pyriformis to the inner side of the sciatic nerve, it then turns over the ischial spine on the outer side of the pudendal vessels, and is directed forwards through the small sacro-sciatic foramen to reach the inner surface of the obturator muscle. This nerve furnishes a small offset to the superior gemellus.

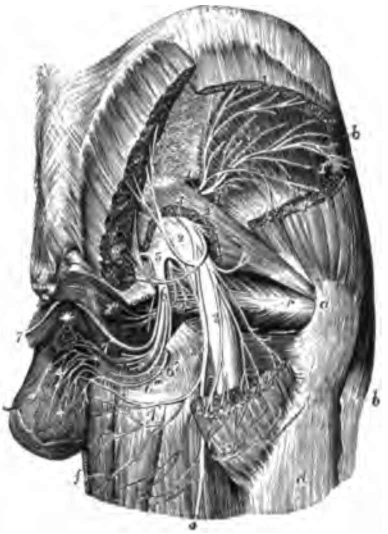

FIG. 68.—BRANCHES OF THE SACRAL PLEXUS IN THE BUTTOCK. (Hirschfeld and Leveillé.) ¼.

a, great trochanter; *b*, tensor fasciæ latæ muscle; *c*, tendon of the obturator internus muscle; *d*, upper part of the vastus lateralis; *e*, coccyx; *f*, gracilis muscle; between *f* and *d*, the adductor magnus, semitendinosus, and biceps muscles, with the lower end of the gluteus maximus; 1, 1, upper branch of the superior gluteal nerve; 1′, 1′, inferior branch of the same nerve; 1″, branch of the nerve to the tensor fasciæ latæ; 2, 2, sacral plexus and sciatic nerve; 2′, muscular twig from the plexus to the pyriformis; 2″, branch to the gemellus superior and obturator internus; 3, posterior cutaneous nerve; 3′, 3′, placed on the upper and lower parts of the divided gluteus maximus, the branches of the inferior gluteal nerve; 3″, the gluteal cutaneous branches of the posterior cutaneous nerve winding round the lower border of the gluteus maximus; 4, the continuation of the posterior cutaneous nerve as posterior cutaneous nerve of the thigh; 4′, inferior pudendal branch of the posterior cutaneous; 5, placed on the lower part of the sacral plexus, points to the origin of the pudendal nerve; 6, its perineal division with its muscular branches; 6′, mesial superficial perineal branch; 6″, lateral superficial perineal; + +, distribution of these nerves and the inferior pudendal on the scrotum; 7, dorsal nerve of the penis.

Varieties.—Occasionally the branch to the superior gemellus is also given off by the nerve to the quadratus; or that muscle may be supplied from both sources. In one instance J. T. Wilson found the nerve to the quadratus continued to the upper part of the adductor magnus.[1]

Superior gluteal nerve. — The superior gluteal nerve arises from the back of the lumbo-sacral cord and first sacral nerve. It leaves the pelvis with the gluteal vessels through the great sacro-sciatic foramen above the pyriformis muscle, and immediately divides into two branches, which run forwards between the gluteus medius and minimus, supplying those muscles and the tensor fasciæ latæ.

The *upper branch* is the smaller and more superficial; it sends its offsets solely to the gluteus medius.

The *lower branch* crosses the middle of the gluteus minimus muscle with the lower branch of the gluteal artery; it sends branches to both the gluteus medius and minimus, and generally perforates the fore-part of the latter muscle to reach the deep surface of the tensor fasciæ latæ, in which it ends.

Varieties.—The superior gluteal sometimes receives fibres also from the second sacral nerve. A branch to the pyriformis muscle may be given off from the lowest root of this nerve.

Inferior gluteal nerve. — The inferior gluteal nerve arises from the back of the plexus, being formed of fibres which are derived from the lumbo-sacral cord, and the first and second sacral nerves. It usually sends a branch downwards to join the commencement of the posterior cutaneous of the thigh, and sometimes the two nerves are more closely connected at their origins. The inferior gluteal nerve turns backwards at the lower border of the pyriformis muscle, and immediately divides into a number of branches which, diverging upwards and downwards, enter the deep surface of the gluteus maximus muscle about midway between its origin and insertion.

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[1] Journ. Anat. xxiii. 354.

Posterior cutaneous nerve of the thigh (*small sciatic*).—This nerve is entirely a sensory nerve, supplying the integument of the lower part of the buttock, the back of the thigh, and the upper part of the back of the leg; it also furnishes branches to the perineum (inferior pudendal or rami perineales).

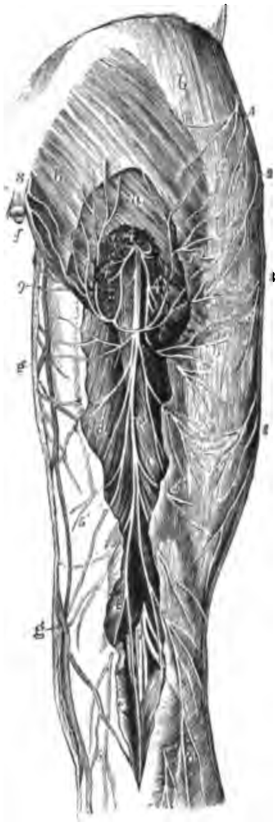

FIG. 64. — POSTERIOR CUTANEOUS NERVES OF THE HIP AND THIGH. (Hirschfeld and Leveillé.) ¼.

a, gluteus maximus muscle, divided at its inferior part to show the posterior cutaneous nerve; *b*, *b*, fascia lata; *c*, *d*, part of the semitendinosus, biceps, and semimembranosus muscles exposed by the removal of the fascia; *e*, gastrocnemius; *f*, coccyx; *g*, saphenous vein; 1, 2, 3, 3, posterior twigs of the lateral cutaneous nerve of the thigh; 4, posterior cutaneous nerve; 4′, 4″, its gluteal cutaneous branches; 5, its continuation; 5′, 5′, its inner and outer femoral cutaneous branches spreading on the fascia of the thigh; 6, 6, its terminal branches descending on the calf of the leg; 7, tibial and peroneal nerves, separating in the popliteal space; 8, posterior divisions of the lower sacral and coccygeal nerves; 9, inferior pudendal nerve.

The nerve takes its origin usually from the back of the upper three sacral nerves by as many roots, the highest of which arises in common with a part of the inferior gluteal nerve. Emerging below the pyriformis muscle, it descends beneath the gluteus maximus muscle, resting on the sciatic nerve, and then along the back of the thigh under cover of the fascia lata to a little beyond the knee. Here it becomes subcutaneous, and its terminal ramifications are distributed to the skin of the calf, one branch accompanying the short saphenous vein and forming a communication with the sural nerve.

Branches. — The *gluteal cutaneous branches* (*nervi clunium inferiores*) are two or three in number, and bend upwards over the lower border of the gluteus maximus muscle, to be distributed to the skin of the lower and outer part of the gluteal region.

The *inferior pudendal nerve* (*rami perineales*) turns inwards below the ischial tuberosity, giving offsets (sometimes separate branches of the nerve) to the skin of the upper and inner part of the thigh, and is continued forwards to the outer part of the scrotum (or external labium pudendi), where its terminal filaments are distributed, after forming communications with the perineal branches of the pudendal nerve.

The *femoral cutaneous branches* are numerous, and arise from both sides of the nerve while it lies beneath the fascia: they supply the skin of the back of the thigh, the larger number passing to the inner side.

Varieties.—In cases of separate origin of the tibial and peroneal nerves, the posterior cutaneous nerve also arises from the sacral plexus in two parts. The ventral portion descends with the tibial nerve below the pyriformis, and gives off the inferior pudendal and inner femoral branches, while the dorsal portion passes through that muscle with the peroneal nerve, and furnishes the gluteal and outer femoral branches. The inferior pudendal nerve sometimes pierces the great sacro-sciatic ligament. The posterior cutaneous may be joined on the back of the thigh by a branch of the sciatic nerve (p. 110). In some cases the posterior cutaneous nerve ends behind the knee, its place in the leg being then taken by a branch of the peroneal.

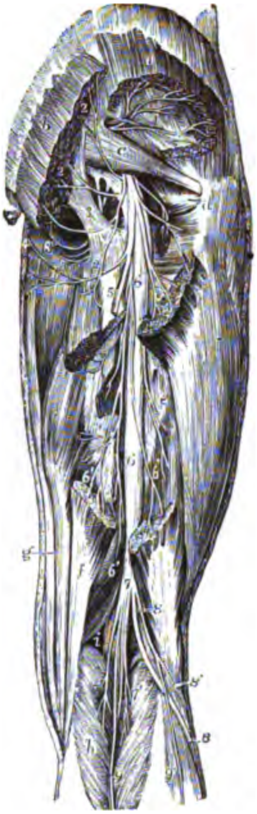

Fig. 65. — Deep posterior nerves of the hip and thigh. (Hirschfeld and Leveillé.) ⅓.

a, gluteus medius muscle; *b*, gluteus maximus; *c*, pyriformis; *d*, placed on the great trochanter, points to the tendon of the obturator internus; *e*, upper part of the femoral head of the biceps; *f*, semitendinosus; *g*, semimembranosus; *h*, gastrocnemius; *i*, popliteal artery; 1, placed on the gluteus minimus muscle, points to the superior gluteal nerve; 2, 2, 2, ramifications of the inferior gluteal nerve; 3, placed on the great sacro-sciatic ligament, points to the pudendal nerve; 3', its further course; 4, inferior pudendal; 5, placed on the upper divided part of the semitendinosus and biceps, points to the divided posterior cutaneous nerve of the thigh; 6, sciatic nerve; 6', 6', some of its muscular branches to the hamstrings; 7, tibial nerve; 7', its muscular or sural branches; 8, peroneal nerve; 8', its lateral cutaneous branch; 9, sural nerve; 9', communicating peroneal branch to the sural nerve.

The **perforating cutaneous nerve** (fig. 67, 10) is a slender branch which arises most frequently from the second and third sacral nerves, and passes backwards through the great sacro-sciatic ligament; it then turns upwards round the lower border of the gluteus maximus, and is distributed to the skin over the inner and lower part of that muscle.

Varieties. — A perforating cutaneous nerve arising as above stated was found by Eisler 22 times in 34 plexuses: in three of these it was conjoined at its origin with the pudendal nerve. Instead of piercing the great sacro-sciatic ligament it may run with the pudendal nerve between the great and small ligaments, or it may pass between the great ligament and the gluteus maximus muscle. In other cases a nerve having a similar distribution (*n. perforans coccygeus major*, Eisler) arises from the third and fourth (fig. 62), or fourth and fifth nerves (fig. 56, 10), and pierces the coccygeus muscle on its way backwards. Its place may also be supplied by a branch of the posterior cutaneous.

Terminal branches.—The **pudendal nerve** (*pudic nerve*) is a short plexiform trunk, which is given off from the lower part of the sacral plexus and distributes branches to the perineum and external organs of generation. Its chief root is usually derived from the third sacral nerve. To this are added others from the fourth and second nerves; and according to Eisler it also receives fibres from the first sacral nerve. The upper roots spring from the front of the ventral divisions of the corresponding sacral nerves. Passing out of the pelvis between the pyriformis and coccygeus muscles, it turns forwards over the attachment of the small sacro-sciatic ligament to the ischial spine (where it is placed on the inner side of the pudic vessels) to enter the small sacro-sciatic foramen. Having thus arrived at the hinder part of the ischio-rectal fossa, the trunk ends by dividing into the following three branches —viz. the inferior hæmorrhoidal nerve, the perineal nerve, and the dorsal nerve of the penis, or clitoris, according to the sex.

The *inferior hæmorrhoidal nerve* (4, 3, (2) *s*) is sometimes derived separately from the sacral plexus; it crosses the ischio-rectal fossa towards the anus and divides into numerous branches which supply the skin of the hinder part of the perineal space and the external sphincter muscle. The most anterior branches form communications with the inferior pudendal and superficial perineal nerves.

The *perineal nerve* (3, 2, 4 *s*) is the largest of the three divisions of the pudendal nerve. It runs forwards along the outer wall of the ischio-rectal fossa, being contained in a special sheath of the obturator fascia below the pudendal vessels, and breaks up into superficial and deep branches.

The *superficial perineal nerves* are two in number, lateral and mesial. The *lateral* or *posterior*, which is the first to leave the perineal trunk, runs forwards along the outer side of the perineal space to the scrotum, and sometimes gives a branch to the adjacent part of the thigh. The *mesial* or *anterior* branch is larger, and runs forwards nearer the middle line, dividing into long slender offsets which are distributed to the integument of the scrotum. The two branches communicate freely together, and the lateral generally receives the connecting filaments from the perineal branches of the posterior cutaneous and inferior hæmorrhoidal nerves. The inferior pudendal (*perineal*) branches of the posterior cutaneous of the thigh and the perineal branches of the pudendal nerve are sometimes named from their distribution *long scrotal nerves* (*nervi scrotales posteriores*).

In the female, these perineal branches terminate in the external labium pudendi (*nervi labiales posteriores*).

The *deep branches* generally arise by a single trunk, and are distributed mainly to the muscles of the perineum. They supply the fore-part of the external sphincter and levator ani muscles, the transversus perinei, ischio-cavernosus, and bulbo-cavernosus. One branch passes inwards through the bulbo-cavernosus muscle, and divides into slender filaments

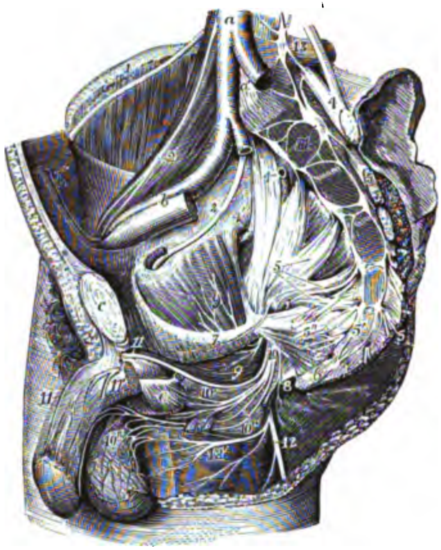

FIG. 66.—RIGHT SIDE OF THE INTERIOR OF THE MALE PELVIS, WITH THE PRINCIPAL NERVES DISPLAYED. (Hirschfeld and Leveillé.) ¼.

The left wall has been removed as far as the sacrum behind and the symphysis pubis in front; the viscera and the lower part of the right levator ani have been removed; *a*, lower end of the aorta; *a'*, placed on the fifth lumbar vertebra, between the two common iliac arteries, of which the left is cut short; *b*, right external iliac vessels; *c*, symphysis pubis; *d*, the divided pyriformis muscle, close to the left auricular surface of the sacrum; *e*, bulb of the urethra covered by the bulbo-cavernosus muscle: the membranous part of the urethra cut short is seen passing into it; 1, on the crest of the ilium, the lateral cutaneous nerve of the thigh passing over the iliacus muscle; 2, on the psoas muscle, the genito-femoral nerve; 3, obturator nerve; 4, 4, on the lumbo-sacral cords: that of the right side points to the gluteal artery cut short; 4', superior gluteal nerve; 5, on the right sacral plexus, points by four lines to the ventral divisions of the four upper sacral nerves, which, with the lumbo-sacral cord, form the plexus; 5', placed on the fifth piece of the sacrum, points to the fifth sacral nerve; 5'', visceral branches from the third and fourth sacral nerves; 6, placed on the lower part of the coccyx, below the coccygeal nerves; 7, the nerve of the levator ani muscle; 8, inferior hæmorrhoidal nerve; 9, nerve of the obturator internus; 10, pudendal nerve; 10', muscular branches of the perineal nerve; 10'', superficial perineal nerves, and on the scrotum the distribution of these nerves and the inferior pudendal nerve; 11, right dorsal nerve of the penis; 11', the nerve on the left crus penis, which is cut short; 12, posterior cutaneous nerve; 12', its inferior pudendal branch; 13, on the transverse process of the fifth lumbar vertebra, the lowest lumbar sympathetic ganglion; 14, on the first piece of the sacrum, the upper sacral sympathetic ganglia; between 14 and 6 are seen the remaining ganglia and sympathetic nervous cords, as well as their union with the sacral and coccygeal nerves, and at 6, the lowest ganglion or ganglion impar.

which penetrate the corpus spongiosum and reach the mucous membrane of the urethra.

The *dorsal nerve of the penis* (2, 3, (1) *s*) is the deepest branch of the pudendal nerve, and accompanies the pudic artery in its course through the deep perineal fascia, and between the layers of the suspensory ligament to the dorsum of the penis, along which it passes as far as the glans, where it divides into filaments for the supply of that part. While passing through the deep perineal fascia, it gives fine twigs for the supply of the constrictor urethræ muscle; and on the dorsum of the penis it is joined by branches of the sympathetic system, and sends outwards numerous offsets to the integument on the upper surface and sides of that organ. Some filaments also penetrate the corpus cavernosum.

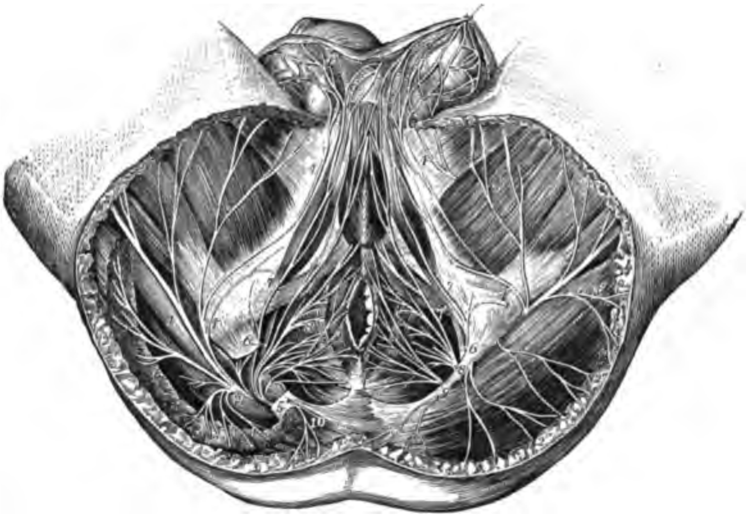

FIG. 67.—DISSECTION OF THE PERINEUM OF THE MALE TO SHOW THE DISTRIBUTION OF THE PUDENDAL AND OTHER NERVES. (Hirschfeld and Leveillé.) ½.

On the right side a part of the gluteus maximus muscle and the great sacro-sciatic ligament have been removed; 1, sciatic nerve of the right side; 2, 2′, on the right side, inferior gluteal nerve; 2″, on the left side, gluteal cutaneous branches of the posterior cutaneous; 3, posterior cutaneous nerve in the thigh; 4, 4, inferior pudendal nerve; 4′, network of this and the superficial perineal nerves in the scrotum; 5, right pudendal nerve; 6, superior branch or dorsal nerve to the penis; 7, lateral superficial perineal branch; 7′, mesial superficial perineal branch; 8, deep or musculo-bulbal branches; 9, inferior hæmorrhoidal nerve; 10, perforating cutaneous nerve.

In the female the *dorsal nerve of the clitoris* is much smaller than the corresponding branch in the male; it is similarly distributed.

Varieties.—In the high form of plexus the pudendal nerve may receive fibres from the fifth lumbar (Eisler). Henle describes and figures a root to the pudendal from the fifth sacral nerve, but this was never met with by Eisler or Paterson. The inferior hæmorrhoidal nerve often pierces the great or the small sacro-sciatic ligament on its way to the perineum (Eisler). The lateral superficial perineal nerve may also pierce the great sacro-sciatic ligament.

SUMMARY.—The pudendal nerve supplies the skin and muscles of the perineum, the penis, and part of the scrotum in the male; and the clitoris, labia, and other corresponding parts in the female. It communicates with the perineal branches of the posterior cutaneous of the thigh.

The sciatic nerve (*great sciatic* or *ischiadic nerve*).—This nerve, the largest nerve in the body, supplies the muscles at the back of the thigh, and by the branches continued from it gives nerves to all the muscles below the knee and to the greater part of the integument of the leg and foot. The several joints of the lower limb receive filaments from it and its branches.

This large nerve is the continuation of the main part of the sacral plexus. It extends from the lower border of the pyriformis muscle to somewhat below the middle of the thigh, where it separates into two large divisions, named the tibial and the peroneal nerves. At first it lies in the hollow between the great trochanter and the ischial tuberosity, covered by the gluteus maximus and resting on the gemelli, obturator internus, and quadratus femoris muscles, in company with the posterior cutaneous nerve and the sciatic artery, and receiving from that artery a branch which runs for some distance in its substance. Lower down it rests on the adductor magnus, and is covered behind by the long head of the biceps muscle.

Branches.—In its course downwards, the sciatic nerve supplies offsets to the hamstring muscles—viz. the semitendinosus, two heads of the biceps, and semimembranosus. A branch is likewise given to the inner part of the adductor magnus.

The branches of the sciatic nerve to the muscles arising from the ischial tuberosity are associated with its tibial division, from which, however, they may be separated up to their origin from the sacral plexus. They are then found to arise in the following order from above downwards: the nerves to the adductor magnus (from 4 and 5 *l*) and semimembranosus (4, 5 *l*, and 1 *s*), these being commonly united in one cord; two branches for the semitendinosus (from 5 *l*, 1, and 2 *s*), one supplying the part of the muscle above, and the other the part below the tendinous inscription; and the nerve of the long head of the biceps (from 1, 2, and 3 *s*). The nerve of the short head of the biceps is united with the division, and according to Paterson may be followed up to 5 *l*, 1, and 2 *s*.

Varieties.—The bifurcation of the sciatic nerve may take place at any point intermediate between the sacral plexus and the lower part of the thigh; and in some cases the two terminal branches arise separately from the sacral plexus (see p. 104). Very rarely the division takes place below the popliteal space (Henle). A branch of the sciatic to join the posterior cutaneous on the back of the thigh is said to be normal by Krause, of frequent occurrence by Henle. In one instance a nerve to the short head of the biceps arose directly from the sacral plexus in union with the inferior gluteal nerve (G. D. Thane). Out of 138 cases recorded by the Collective Investigation Committee[1] the whole of the sciatic nerve emerged from the pelvis below the pyriformis muscle in 118; in 17 cases the nerve left as two trunks, of which one, the peroneal, pierced the pyriformis muscle; while in the remaining three the whole nerve passed through this muscle.

Tibial nerve (*internal popliteal* and *posterior tibial nerves*).—The larger of the two divisions of the sciatic nerve arises under cover of the hamstring muscles, and following the same direction as the parent trunk passes down the middle of the popliteal space. Below this space it again becomes deeply situated by going down the back of the leg beneath the gastrocnemius and soleus, and finally it becomes subcutaneous on the mesial side of the tendo Achillis and ends by dividing between the calcaneus and the internal malleolus into the mesial and lateral plantar nerves. The nerve lies at first at a considerable distance from the popliteal artery, at the outer side and nearer to the surface; but from the knee-joint downwards the nerve, continuing a straight course, is close behind the artery, and then crosses it rather to the inner side. It passes down the leg with the posterior tibial artery, lying for a short distance on the inner side of the vessel and afterwards on the outer side, the artery inclining inwards from its origin, while the nerve takes a straighter course.

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[1] Journ. Anat. and Phys. xxxi.

When the tibial nerve is described as two nerves, the upper one (internal popliteal) is said to terminate by becoming continuous with the lower (posterior tibial) at the lower border of the popliteus muscle.

The tibial nerve supplies branches to the knee and ankle joints, to the superficial and deep muscles of the back of the leg, and to the skin of the leg and foot.

The *articular branches* to the knee-joint are given off from the upper part of the tibial trunk, and are generally three in number; two of them accompany the upper and lower articular arteries of the inner side of the knee-joint, the third follows the middle or azygos artery. These nerves pierce the ligamentous tissue of the joint. The upper one is often wanting.

One or two *articular filaments* pass from the tibial nerve close above its division to the inner side of the ankle-joint (Rüdinger).

The *muscular branches* arise from the nerve while it is contained in the popliteal space and as it lies under the superficial muscles of the calf. They include two nerves to the *gastrocnemius* (1, 2 *s*)—one to each head of the muscle; a small nerve to the *plantaris* (4, 5 *l*, 1 *s*), derived either from the branch to the lateral head of the gastrocnemius, or directly from the main trunk; a considerable branch to the *soleus* (5 *l*, 1, 2 *s*), which enters the muscle on its posterior aspect, close to the upper border; and a nerve to the *popliteus* (4, 5 *l*, 1 *s*). The last branch arises somewhat lower down, and is more deeply placed, than the others; it descends on the outer side of the popliteal vessels, gives off filaments to the superior tibio-fibular articulation, to the tibia, and to the interosseous membrane, and then turns beneath the lower border of its muscle, which it penetrates on the deep or anterior surface. The branch to the tibia enters the shaft of the bone with the medullary artery; that to the interosseous membrane is a long slender twig which, after supplying filaments to the anterior and posterior tibial arteries, is continued downwards in the membrane to end in the inferior tibio-fibular articulation, and the periosteum of the lower part of the tibia; small Pacinian corpuscles occur on the filaments passing to the bone and ligaments. A little below the popliteal space branches arise for the supply of the *tibialis posticus*, the *flexor longus digitorum*, and the *flexor longus hallucis*; and a second nerve is furnished to the *soleus*, piercing the deep surface of the muscle.

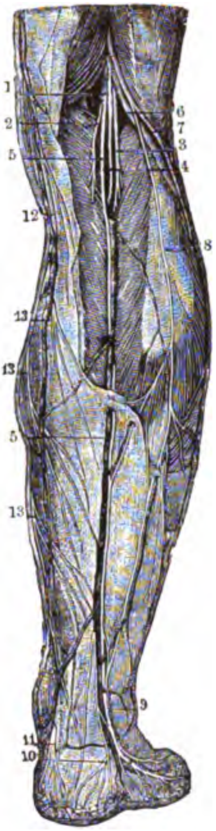

FIG. 68. — POSTERIOR CUTANEOUS NERVES OF THE LEG. (From Sappey, after Hirschfeld and Leveillé.)

1, tibial nerve; 2, branch to the mesial head of the gastrocnemius muscle; 3, 4, branches to the lateral head and plantaris; 5, sural nerve; 6, peroneal nerve; 7, lateral cutaneous branch of the leg; 8, peroneal communicating branch, descending to unite with the sural, 9; 10, calcaneal branch from this nerve; 11, calcaneal and plantar cutaneous branches from the tibial nerve; 12, saphenous nerve; 13, posterior branches of this nerve.

The *fibular branch* is a long slender offset which arises in common with the nerves to the deep muscles of the leg, and descends, beset with Pacinian corpuscles, in the canal of the peroneal vessels as far as the ankle. It gives off filaments to the vessels which it accompanies, to the shaft of the fibula with the medullary artery, and to the periosteum covering that bone (Rauber).

The *cutaneous branches.*—The *nervus suralis* (*short saphenous*) (1, 2 *s*) descends along the leg, in the furrow between the heads of the gastrocnemius muscle, to about midway between the knee and the foot. Here it perforates the fascia, and a little lower down is usually joined by a branch from the peroneal nerve. After receiving this communicating branch, the sural nerve descends beneath the integument near the outer side of the tendo Achillis in company with the short saphenous vein, and turns forwards below the external malleolus to end in the skin on the outer side of the little toe, forming also a communication on the dorsum of the foot with the lateral division of the musculo-cutaneous nerve. While turning round the external malleolus, the sural nerve gives off *lateral calcaneal branches* to the skin on the outer side of the heel; and other filaments pass to the ankle-joint and the astragalo-calcaneal articulation (Rüdinger).

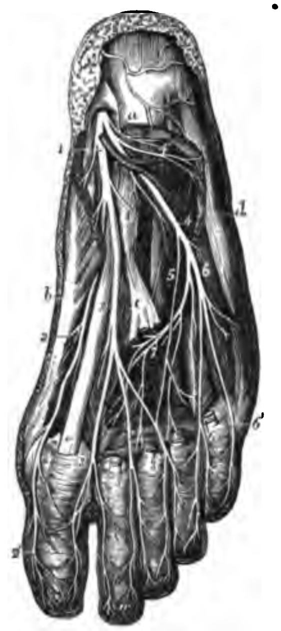

FIG. 69. — SUPERFICIAL AND DEEP DISTRIBUTION OF THE PLANTAR NERVES. (After Hirschfeld and Leveillé, slightly modified.) (Allen Thomson.) ⅓.

Parts of the flexor brevis digitorum, abductor hallucis, abductor minimi digiti, and the tendons of the flexor longus digitorum, together with the lumbricales muscles, have been removed so as to bring into view the adductor transversus and interosseous muscles in the middle of the foot.

a, upon the posterior extremity of the flexor brevis digitorum, near which, descending over the heel, are seen ramifications of the calcaneal branch of the tibial nerve; *b*, abductor hallucis; *c*, tendon of the flexor longus digitorum, divided close to the place where it is joined by the flexor accessorius; *d*, abductor minimi digiti; *e*, tendon of the flexor longus hallucis between the two portions of the flexor brevis hallucis; 1, mesial plantar nerve giving twigs to the abductor hallucis, and 1', a branch to the flexor brevis digitorum, cut short; 2, inner branch of the mesial plantar nerve, giving branches to the flexor brevis hallucis, and forming, 2', the internal collateral nerve of the great toe; 3, continuation of the mesial plantar nerve, dividing into three branches, which form, 3', 3', 3', the plantar digital nerves of the first and second, second and third, and third and fourth toes; 4, lateral plantar nerve; 4', its branch to the abductor minimi digiti; 5, twig of union between the plantar nerves; 6, superficial branch of the lateral plantar nerve, dividing into 6', 6', the collateral digital nerves of the fourth and fifth toes and the external nerve of the fifth; 7, deep branch of the lateral plantar nerve.

The *calcaneo-plantar nerve* (1, 2 *s*) is given off by the tibial in the lower part of the leg, and becomes superficial by piercing the internal annular ligament. It divides into *lateral calcaneal branches* which ramify in the integument on the inner side of the heel, and *plantar cutaneous branches* which supply the skin of the inner and hinder part of the sole.

Varieties.—The union between the sural nerve and the communicating branch of the peroneal nerve occurs in some cases higher than usual, occasionally even at or close to the popliteal space. It sometimes happens that the communication between the nerves is altogether wanting; in which case the cutaneous nerve to the foot is generally continued from the tibial branch. The area of distribution of the sural nerve in the foot is often increased, so that it supplies in part or wholly the outer one and a-half, or even two and a-half toes on their dorsal aspect: in these cases the peroneal communicating branch is said to be of larger size than usual. Occasionally the sural nerve ends on the outer border of the foot, without reaching the toes.

The **mesial plantar** (*internal plantar*) (4, 5 *l*, 1 *s*), slightly the larger of the two nerves to the sole of the foot into which the tibial divides, accompanies the mesial or smaller plantar artery, and supplies nerves to both sides of the inner three toes and to one side of the fourth. From the point at which it separates from the tibial nerve it is directed forwards under cover of the first part of the abductor of the great toe; then, passing between that muscle and the short flexor of the toes, it gives off its first digital branch for the great toe, and divides about the middle of the foot into three other digital branches. The outermost of these branches communicates with the lateral plantar nerve. The distribution of this nerve in the foot closely resembles that of the median nerve in the hand.

Branches.—Muscular branches are supplied to the abductor hallucis and flexor brevis digitorum.

An *articular filament* passes deeply between the abductor hallucis and the tendons of the long flexors of the toes to supply the joints between the astragalus, the navicular, and the inner two cuneiform bones (Rüdinger).

Small *plantar cutaneous branches* perforate the plantar fascia to ramify in the integument of the sole of the foot.

The *digital branches* are named numerically from within outwards: the outer three pass from under cover of the plantar fascia near the clefts between the toes. The first or innermost branch continues single, but the other three bifurcate to supply the adjacent sides of two toes. They are distributed as follows:

The *first* digital branch is destined for the inner side of the great toe; it becomes subcutaneous farther back than the others, and sends off a branch to the flexor brevis hallucis muscle.

The *second* branch, having reached the interval between the first and second metatarsal bones, furnishes a small twig to the first lumbricalis muscle, and bifurcates behind the cleft between the great toe and the second to supply their contiguous sides.

The *third* digital branch, corresponding with the second interosseous space, divides in a manner similar to that of the second branch into two offsets for the sides of the second and third toes.

The *fourth* digital branch, distributed to the adjacent sides of the third and fourth toes, usually has a communication with the lateral plantar nerve.

Along the sides of the toes, cutaneous and articular filaments are given from these digital nerves; and, opposite the ungual phalanx, each sends a dorsal branch to the pulp beneath the nail, and then runs on to the ball of the toe, where it is distributed like the nerves of the fingers. Pacinian corpuscles are attached at intervals to these nerves.

The **lateral plantar** (*external plantar*, 1, 2 *s*) completes the supply of digital nerves to the toes, furnishing branches to the little toe and half the fourth; it also gives a deep branch of considerable size which is distributed to several of the short muscles in the sole of the foot. There is thus a great resemblance between the distribution of this nerve in the foot and that of the ulnar nerve in the hand.

The lateral plantar nerve runs obliquely forwards towards the outer side of the foot, along with the lateral plantar artery, between the flexor brevis digitorum and the flexor accessorius, as far as the interval between the former muscle and the abductor of the little toe. Here it divides into a superficial and a deep branch, having previously furnished offsets to the abductor minimi digiti and the flexor accessorius, as well as a filament through the last muscle to the calcaneo-cuboid articulation (Rüdinger).

The *superficial portion* separates into two *digital branches*, which have the same general arrangement as the digital branches of the mesial plantar nerve. The outermost of these is undivided, and runs along the outer side of the little toe; it is smaller than the other, and pierces the plantar fascia farther back. The short flexor muscle of the little toe, and sometimes one or both of the interosseous muscles of the fourth space, receives branches from this nerve.

The larger digital branch usually communicates with the mesial plantar nerve, and bifurcates near the cleft between the fourth and fifth toes to supply one side of each.

The *deep* or *muscular part* of the lateral plantar nerve dips into the sole of the foot with the lateral plantar artery, under cover of the tendons of the flexor muscles and the accessorius, and terminates in numerous branches for the following muscles: all the interosseous (dorsal and plantar) except occasionally one or both of those in the fourth space, the outer three lumbricales, the adductor transversus and adductor obliquus hallucis. This part of the nerve also furnishes *articular filaments* to the tarso-metatarsal, and frequently to the metatarso-phalangeal joints, as well as minute *perforating branches*, which pass upwards through the posterior ends of the intermetatarsal spaces to join the interosseous branches of the anterior tibial nerve (Rüdinger).

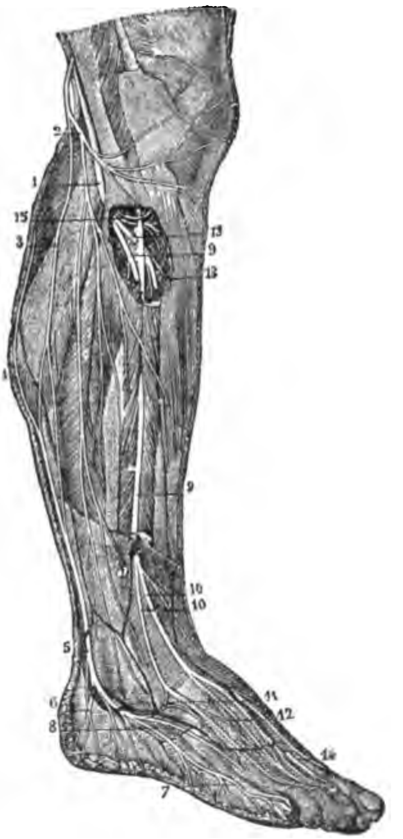

FIG. 70.—CUTANEOUS NERVES OF OUTER SIDE OF THE LEG AND FOOT. (From Sappey, after Hirschfeld and Leveillé.) $\frac{1}{5}$.

1, peroneal nerve; 2, its lateral cutaneous branch; 8, peroneal communicating branch which unites with 5, the sural nerve; 6, calcaneal branch of sural; 7, lateral dorsal digital branch of the fifth toe; 8, dorsal digital branch of the fourth and fifth toes; 9, 9, musculo-cutaneous nerve; 10, 10, its two divisions; 11, union with the sural; 12, communication between its lateral and mesial branches; 13, anterior tibial nerve, shown by the removal of a part of the muscles; 14, its inner terminal branch, emerging in the space between the first and second toes, where it gives the collateral dorsal digital branches to their adjacent sides; 15, recurrent articular nerve.

Out of ten dissections by Brooks, the lumbricales were supplied as stated above in nine. In the tenth case the first and second lumbricales received branches from both the mesial and lateral plantar nerves.[1] The branch of the lateral plantar nerve to the second lumbricalis runs forwards beneath the adductor transversus hallucis, and then turns backwards over that muscle to reach its destination. Cruveilhier describes the branch to the third lumbricalis as piercing the adductor transversus hallucis. The deep part of the lateral plantar nerve rarely gives a branch to the outer head of the flexor brevis hallucis (normal according to Henle and Schwalbe).

SUMMARY OF THE TIBIAL NERVE.—This nerve supplies all the muscles of the back of the leg and sole of the foot, the articulations of the knee, ankle, and foot, the bones and vessels of the leg, and the integument of the plantar aspect of the toes, the sole of the foot, and in part that of the lower half of the back of the leg.

Peroneal nerve (*common peroneal* or *external popliteal*).—This nerve descends obliquely along the outer side of the popliteal space, lying close to the biceps muscle. Continuing downwards over the lateral head of the gastrocnemius muscle (between it and the biceps) and below the head of the fibula, the nerve turns round that bone and, passing between it and the peroneus longus muscle, divides into the *anterior tibial* and the *musculo-cutaneous nerves.*

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[1] Journ. Anat. xxi. 575.

Some articular and cutaneous branches are derived from the peroneal nerve before its final division.

The *articular branches* are conducted to the outer side of the capsular ligament of the knee-joint by the upper and lower articular arteries of that side. They sometimes arise together, and the upper one occasionally springs from the sciatic nerve before the bifurcation. From the lower branch a filament is given to the superior tibio-fibular articulation (Rüdinger).

From the place of division of the peroneal nerve, a branch (often double) called the *recurrent articular nerve* ascends through the tibialis anticus with the anterior tibial recurrent artery; its fibres terminate mainly in that muscle, but filaments may be traced to the superior tibio-fibular articulation, the periosteum over the outer tuberosity of the tibia, and the fore-part of the knee-joint.

The *cutaneous branches* (5 *l*, 1, 2 *s*), generally two in number, supply the skin on the back part and outer side of the leg.

The *peroneal* or *fibular communicating branch,* which usually joins the sural nerve below the middle of the back of the leg, is the largest of these nerves. In some instances it continues as a separate branch, and its cutaneous filaments reach down to the heel or on to the outer side of the foot.

The *lateral cutaneous branch of the leg* (*nervus cutaneus suræ lateralis*), often arising in conjunction with the foregoing, extends along the outer side of the leg to the middle or lower part, sending offsets both backwards and forwards.

In some cases there is another cutaneous branch which arises from the upper part of the peroneal nerve, and ramifies over the back of the calf, taking the place of the posterior cutaneous nerve below the knee.

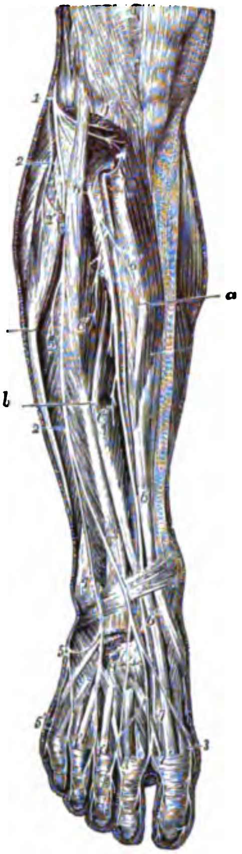

FIG. 71.—DISTRIBUTION OF THE BRANCHES OF THE PERONEAL NERVE ON THE FRONT OF THE LEG AND DORSUM OF THE FOOT. (After Hirschfeld and Leveillé.) $\frac{1}{5}$.

The upper part of the peroneus longus muscle has been removed, the tibialis anticus, the long extensor of the great toe, and the peroneus longus are drawn apart in the leg by hooks marked *a*, *b*, and *c*, and the tendons of the extensor muscles have been removed on the dorsum of the foot; 1, peroneal nerve, winding round the outer part of the fibula; 1', its recurrent articular branches exposed by the dissection of the upper part of the tibialis anticus muscle; 2, 2, musculo-cutaneous nerve; 2', 2', twigs to the long and short peroneal muscles; 3, 3', mesial branch of the musculo-cutaneous nerve; 4, 4', 4', its lateral branch; 5, sural nerve, uniting at two places with the lateral branch of the musculo-cutaneous; 5', its branch to the outer side of the fifth toe; 6, placed on the upper part of the extensor longus digitorum, marks the anterior tibial nerve passing beneath the muscle; 6, placed farther down on the tendon of the tibialis anticus, points to the nerve as it lies in front of the anterior tibial artery; 6', 6', its muscular branches in the leg; 6'', on the tendon of the extensor longus hallucis, points to the anterior tibial nerve after it has passed into the foot behind that tendon; 7, its mesial branch, uniting with a twig of the musculo-cutaneous, and giving the dorsal digital nerves to the adjacent sides of the first and second toes; 8, distribution of its lateral branch to the extensor brevis digitorum and tarsal articulations.

The **musculo-cutaneous nerve** (*superficial peroneal nerve,* 4, 5 *l*, 1 *s*) descends between the peronei muscles and the long extensor of the toes, and reaches the surface by perforating the fascia in the lower part of the leg on the anterior aspect. It then divides into two branches, distinguished as lateral and mesial, which proceed to the toes. The two branches sometimes perforate the fascia at different spots.

Branches.—Muscular branches are given to the peroneus longus and peroneus brevis.

Cutaneous branches given off near the primary division are distributed to the lower part of the leg.

The *mesial branch* of the nerve, passing forwards along the dorsum of the foot, furnishes one branch to the inner side of the great toe, and another to the contiguous sides of the second and third toes. It also gives offsets which extend over the inner ankle and side of the foot. This nerve communicates with the saphenous nerve on the inner side of the foot, and with the nerve between the first and second toes.

The *lateral branch,* smaller than the mesial, descends over the foot towards the fourth toe, which, together with the contiguous borders of the third and fifth toes, it supplies with branches. Cutaneous nerves, derived from this branch, spread over the outer ankle and the outer side of the foot, where they are connected with the sural nerve.

The dorsal digital nerves are continued on to the last phalanges of the toes.

The number of toes supplied by each of the two divisions of the nerve is liable to vary; together, these nerves commonly supply all the toes on the dorsal aspect, excepting the outer side of the little toe, which receives a branch from the sural nerve, and the adjacent sides of the great toe and the second toe, to which the anterior tibial nerve is distributed: with this latter branch, however, it generally communicates.

Varieties.—The nerve is often reduced in size, the deficiency being supplied by the sural nerve. Less frequently the mesial branch is replaced to a greater or less extent on the toes by the anterior tibial nerve. The number of toes supplied by the musculo-cutaneous nerve is seldom increased. (On variations in the nerves of the dorsum of the foot, and their relative frequency, see the Second Annual Report of the Committee of Collective Investigation of the Anat. Soc., by Arthur Thomson, Journ. Anat. xxvi. 1891.) T. H. Bryce[1] described a nerve which arises from the branch to the peroneus brevis and is continued downwards to the peroneus quartus. After supplying this muscle it may be prolonged on to the dorsum of the foot and furnish twigs to the extensor brevis digitorum.

Anterior tibial nerve (*deep peroneal nerve*).—The anterior tibial nerve (4, 5 *l*, 1 *s*), commencing between the fibula and the peroneus longus, inclines obliquely beneath the long extensor of the toes to the fore-part of the interosseous membrane, and there comes into contact with the anterior tibial vessels; with these vessels it descends to the front of the ankle-joint, where it divides into a lateral and a mesial branch. The nerve reaches the anterior tibial artery about the junction of the upper with the second fourth of the leg, and is thence placed in front of the vessels as far as the ankle, at which spot it is usually on their outer side.

Branches.—Muscular branches.—In its course along the leg, the anterior tibial nerve gives offsets to the adjacent muscles—namely, the tibialis anticus, the extensor longus digitorum, the extensor proprius hallucis, and the peroneus tertius.

An *articular filament* for the ankle-joint arises from the lower part of the nerve.

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[1] Proc. Anat. Soc. July 1896.

The *lateral branch* of the anterior tibial nerve turns outwards over the tarsus beneath the short extensor of the toes; and, having become enlarged (like the posterior interosseous nerve on the wrist), breaks up into branches which supply the short extensor muscle and the articulations of the foot.

The *mesial branch*, continuing onwards in the direction of the anterior tibial nerve, accompanies the dorsal artery of the foot to the first interosseous space, and ends in two branches, which supply the integument on the neighbouring sides of the great toe and the second toe on their dorsal aspect. It communicates with the mesial division of the musculo-cutaneous nerve.

From the mesial branch one, and from the lateral two or three, slender *interosseous branches* are sent forwards to the intermetatarsal spaces, where they are joined by the perforating twigs of the lateral plantar nerve (p. 114). They supply filaments to the tarso-metatarsal articulations and the periosteum of the metatarsal bones, and terminate in the metatarso-phalangeal joints. The second and sometimes the first of these nerves give twigs also to the dorsal interosseous muscles upon which they lie (Rüdinger, Cunningham).

Varieties.—Occasionally the anterior tibial nerve supplies also the inner side of the great toe, or the adjacent sides of the second and third toes. In one case the anterior tibial nerve sent branches to the outer three and a-half toes, the great toe and the inner half of the second being supplied by the musculo-cutaneous.[1] Very rarely the digital branches are altogether wanting. Absence of the cutaneous portions of the musculo-cutaneous and of the anterior tibial and of the branch of the anterior tibial to the extensor brevis digitorum is recorded by Harman,[2] their places being taken by the saphenous and sural nerves.

SUMMARY OF THE PERONEAL NERVE.—This nerve supplies, besides articular branches to the knee, ankle, and foot, the muscles and integument of the outer side and front of the leg and dorsum of the foot. It gives the peroneal communicating branch to the sural nerve, and communicates with the saphenous nerve.

MORPHOLOGY OF THE CEREBROSPINAL NERVES.

SPINAL NERVES.—**Segmentation.**—The spinal nerves in their arrangement as they leave the vertebral column exhibit in a marked degree the character of segmentation. This is not the case, however, at their attachment to the spinal cord, where the filaments of both the ventral and dorsal roots form each a nearly continuous series along the whole length of the cord. In their connexion with the grey matter of the spinal cord there is again evidence of a segmental arrangement, which appears not to correspond exactly to the segmentation seen in the nerve-trunks, for it seems probable that the fibres composing one dorsal root, for example, may be connected with more than one segment of the spinal cord.

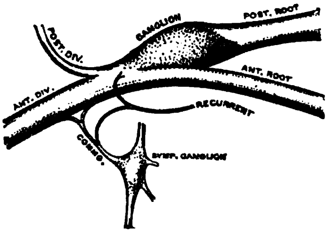

FIG. 72. — PLAN OF THE MODE OF BRANCHING OF A SEGMENTAL NERVE. (G. D. Thane.)

Mode of division.—A typical segmental nerve, such as the sixth thoracic, on leaving the vertebral canal, divides at once into two parts, which are known as the *ventral* or *anterior* and the *dorsal* or *posterior primary divisions*. In addition to these, the trunk also gives off a small *recurrent* or *meningeal branch* to the interior of the spinal canal, and the ventral division furnishes a *branch to the sympathetic*. The primary branching of the nerve may thus be looked upon as a separation into four parts, of which the ventral, dorsal, and recurrent divisions are said to be *somatic*, while the offset to the sympathetic is usually called *visceral* or *splanchnic* (*ramus visceralis*). The latter term, although often convenient, is, however, not strictly accurate, since the sympathetic division contains, in addition to visceral fibres, other fibres which influence the unstriped muscles of the vessels and skin of the trunk and limbs, parts which are of somatic origin.

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[1] F. T. Roberts, Liverpool Med. and Surg. Reports, vi. 1867.
[2] Proc. Anat. Soc. February 1899.

Dorsal primary divisions.—These supply the dorso-lateral muscle of the segment and the overlying integument. As a rule, each is divided into mesial and lateral branches, corresponding to the longitudinal cleavage of the dorso-lateral muscle, and from one only of these an offset passes to the skin. The first cervical nerve has no cutaneous offset; while the last two sacral and the coccygeal nerves give off no muscular branches, as the dorso-lateral muscle terminates at the fourth sacral vertebra, and therefore they do not divide into the usual two branches. Cutaneous branches are not usually furnished by those nerves, the ventral divisions of which occupy a central position in the limb-plexuses (lower three cervical and lower two lumbar nerves).

Ventral primary divisions.—In the primitive condition the ventral primary division of a segmental nerve supplies the ventro-lateral muscle of the segment and a corresponding zone of skin. The *cutaneous* or *perforating branches* are two in number—a *lateral*, which again divides into anterior and posterior branches, and an *anterior*. This arrangement is, however, retained only in the nerves from the second thoracic to the first lumbar inclusive. Above and below the region thus indicated the primitive condition is much modified by the union of the nerves in plexuses, in great part for the supply of the limbs. But the cutaneous distribution of each of these nerves is to a definite continuous area of skin, altered in shape and position in consequence of growth-changes, and in the case of the central limb-nerves shifted so much that all connexion with the trunk is lost.

The area of skin supplied by a segmental nerve may be termed its *dermatome*, the name *myotome* being applied to the muscle-mass it innervates, and that of *sclerotome* to the surface of bone to which this muscle-mass is attached (Bolk).

Nerves of the limbs.—As to the morphological nature of the limb-nerves, it is held by Paterson, Eisler, and others that they represent the whole of the ventral primary divisions of segmental nerves, but it seems probable that the view enunciated by Goodsir and supported by Thane—namely, that the limb-nerves represent greatly developed lateral branches of the ventral divisions—is the better founded. At the same time it is to be noticed that the increase of the lateral branch for the supply of the limb is accompanied by a reduction of the other portions of the segmental nerve, which proceeds so far that the anterior and posterior cutaneous offsets, as well as the visceral branch, are all wanting in the case of the central nerves of the limb-plexuses.

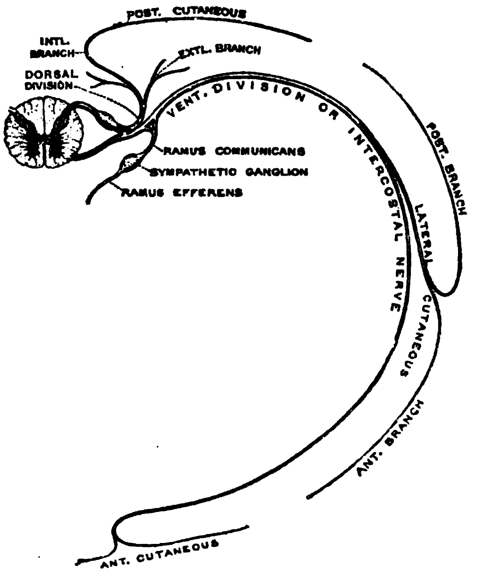

FIG. 78.—PLAN OF AN UPPER THORACIC NERVE, SHOWING THE TYPICAL MANNER OF BRANCHING OF THE DORSAL AND VENTRAL PRIMARY DIVISIONS OF A SEGMENTAL NERVE. (G. D. Thane.)

The transition from the typical segmental nerves to the modified form met with in the limbs takes place gradually. At the upper part of the trunk the third thoracic nerve has the typical character. The second differs but little, its posterior cutaneous branch is drawn out over the scapula, and its lateral branch becomes enlarged and extends down the arm, forming a connexion with the brachial plexus, while some of the fibres belonging to this division often begin to take a shorter course to the plexus through the communication with the first thoracic nerve (p. 86). In the first thoracic nerve the lateral branch, greatly enlarged, passes directly into the brachial plexus, the anterior and posterior cutaneous offsets are small, and sometimes wanting, and its contribution to the sympathetic is less than that of the second. The eighth, seventh, and sixth cervical nerves consist almost wholly of large lateral offsets; the anterior and posterior cutaneous and the visceral branches are suppressed, and the supply from the ventral primary division to trunk-muscles is represented only by the twigs to the scaleni and longus colli. With the fifth cervical nerve the posterior cutaneous branch reappears; and in the fourth, third, and second nerves the lateral offsets are freed from the limb-plexus (except the fourth to a slight extent in some cases), and furnish the superficial branches of the cervical plexus, the lower of which are, however, drawn out over the root of the limb, while anterior perforating branches are wanting.

At the lower part of the trunk, the twelfth thoracic and first lumbar nerves have the characteristic segmental disposition, but their posterior and lateral perforating (cutaneous) branches are drawn down over the root of the limb, as is the case also to a slight extent with a part of the anterior perforating branch of the first lumbar (ilio-inguinal nerve), while a small part of the fibres of this nerve often passes into the limb-plexus. The second lumbar nerve is distinctly intermediate in character, since it possesses all the branches of a segmental nerve, although its larger part passes into the limb-plexus. Its anterior perforating branch is represented by the genital division of the genito-femoral, and its lateral cutaneous offset by the fibres passing to the femoral division of the genito-femoral and to the lateral cutaneous nerve. The third lumbar nerve has a posterior perforating offset, but it consists mainly of a large lateral division passing into the plexus; an anterior perforating branch is wanting, and the contribution to the sympathetic is very small or absent. The fourth lumbar is purely a limb-nerve, the posterior and anterior cutaneous and the visceral offsets being suppressed. The fifth lumbar is like the fourth, except that it may have a small posterior cutaneous offset; and this branch is regularly present in the succeeding nerves. With the second sacral nerve the contribution to the limb-plexus diminishes, the visceral branch reappears, the lateral cutaneous branch begins to be more independent in the posterior cutaneous of the thigh and perforating cutaneous nerves, and the continuation of the trunk to form an anterior perforating offset is to be recognised in the pudendal nerve. The third sacral furnishes only a small contribution to the limb-plexus, and both it and the fourth sacral have the usual constitution of segmental nerves, but their ventral primary divisions are more or less closely united in the pudendal nerve. Of the branches of the latter, the inferior hæmorrhoidal probably corresponds to a lateral perforating offset, while the perineal division and the dorsal nerve of the penis represent anterior perforating offsets.

In the foregoing sketch it has been shown that the lateral branches of the ventral primary divisions are enlarged and carried outwards to supply the integument of the limbs. The cutaneous offsets of some of the dorsal primary divisions are also drawn out to a slight extent over the roots of the limbs (especially the lower), but they do not enter into the plexuses. The anterior perforating branches, however, are not extended to the limbs, except the first lumbar to a slight degree where the lower limb impinges upon the area of these nerves. The supply of the muscles of the limbs by lateral branches of ventral primary divisions offers no difficulty, since these muscles are derived from the superficial layer of the great ventro-lateral muscle; and the obliquus externus, the sole trunk-muscle of this layer (the pectorales, serratus magnus, latissimus dorsi, &c., being limb-muscles, and deriving their nerves from the limb-plexus), is supplied by the lateral cutaneous branches of intercostal nerves.

The number of nerves entering the limb-plexus is subject to some variation, not only in different animals, but also in different individuals of the same species. In man, the *brachial plexus* is formed mainly by the lower four cervical and first thoracic nerves, but contributions are often furnished by either or both of the fourth cervical and second thoracic: the number varies therefore from five to seven. The lower limb-plexus comprises the greater part, but not the whole, of both the lumbar and sacral plexuses, and the name *lumbo-sacral* or *crural plexus* may be used for the sum of the nerves constituting the limb-plexus. Into this enter usually seven nerves—viz. the lower four lumbar and the upper three sacral—but the first lumbar nerve in some cases also furnishes a branch, in rare instances even the last thoracic nerve; while at the opposite end the offset from the third sacral may be wanting, or in extreme cases of low form of plexus the fourth sacral may be drawn in (cf. pp. 92 and 93).

In the case of the brachial plexus all the nerves have the same relation to the shoulder-girdle, passing behind the clavicle. With the lumbo-sacral plexus the arrangement is different: in association with the greater development of the ventral portion of the limb-girdle the nerves are separated as they enter the limb—one set, the lateral cutaneous and femoral, passing in front of the pubic portion of the girdle; a second, the obturator, passing between the pubic and ischial portions of the girdle; and a third, the largest, the gluteal, sciatic, &c., passing behind the ischial portion of the girdle—the *prezonal, diazonal*, and *metazonal nerves* of Fürbringer. Thus there is brought about the separation of the lumbar and sacral plexuses of descriptive anatomy; and the *nervus furcalis* is simply the nerve (entering into loops like the others) which lies at the boundary between the pre- and dia-zonal nerves on the one hand and the metazonal nerves on the other.

As to the significance of the plexuses, it may be remarked in the first place that the term ‘plexus’ is somewhat misleading. The so-called ‘plexuses’ are not interlacements of the spinal nerves, but a temporary union of the fibres of adjacent spinal nerves, and this is probably due to the multiple origin of the nerves of distribution, so that most of the offsets of the plexus contain fibres derived from two or more segmental nerves. This multiple origin is intimately related to the fusion of the myomeres (myotomes) from which the muscles of the limbs are derived, and in association with this is the multiple innervation of individual muscles. A similar union is seen between the lower intercostal nerves before supplying the broad muscles of the abdomen, in which the constituent myomeric elements are fused so that these muscles are *polymeric* and *polyneural*; whereas such communications are much less frequent between the upper intercostal nerves, which are distributed to the *monomeric* and *mononeural* intercostal muscles, &c. Similarly also with the cutaneous offsets, the plexuses afford the means by which the fibres of two or more segmental nerves pass down the limb in a single trunk. Gegenbaur and Fürbringer look upon the plexuses of the limbs as the result of the shifting of the latter along the vertebral column in the course of phylogenetic development, but it is extremely doubtful whether this shifting of the limbs has taken place to the extent supposed by them, and it is difficult to explain in this way the presence of the communications between the lower intercostal nerves while they are absent between the upper nerves, or the formation of the pudendal plexus. It does not appear that the plexuses have a physiological significance, so far at least as the muscles are concerned, beyond the provision of the multiple supply—that is, the mingling of the nerves in the plexuses does not seem to be necessarily related to any functional grouping of the muscles supplied.

The nerves entering the limb-plexuses show a remarkable division, the significance of which was first pointed out by Paterson, into *ventral* or *anterior* and *dorsal* or *posterior portions*, corresponding to the primary subdivisions of the limb-musculature. The dorsal and ventral divisions of a nerve entering the limb are regarded by Paterson and others, who consider that the limb-nerve represents the whole ventral primary division of a spinal nerve, as corresponding respectively to the lateral offset and the anterior portion of a segmental nerve. The ventral divisions of the brachial nerves form the inner and outer cords of the plexus, and the dorsal divisions the posterior cord of the plexus. The ventral divisions of the lumbo-sacral nerves include the obturator, tibial, and some smaller branches, while the dorsal divisions furnish the lateral cutaneous, femoral, peroneal, gluteal, and some other nerves (p. 104). In their cutaneous distribution, while as a general rule the skin overlying ventral muscles is supplied by nerves of ventral origin, and that over dorsal muscles by the dorsal divisions of the nerves, the limits are not strictly kept, and the territory of the one group is often greatly extended at the expense of the other (cf. figs. 84, 85, and 86). In the following table the nerves of each group are shown, together with the probable homologies of the nerves of the two limbs, so far as they can be traced:

CLASSIFIED TABLE OF THE NERVES OF THE LIMBS, WITH THEIR PROBABLE HOMOLOGIES.

UPPER LIMB.	LOWER LIMB.
Dorsal branches.	*Dorsal branches.*
N. to rhomboids.	
Long thoracic.	
Suprascapular	Branches of femoral to iliacus.
Subscapular (2) Circumflex: muscular part	Superior gluteal. N. to pyriformis. Inferior gluteal.
Circumflex: cutaneous part	Posterior cutaneous: gluteal branches and outer part of femoral division.
	Perforating cutaneous.
Musculo-spiral.	
Branches in arm	Lateral cutaneous. Femoral.[1]
Rest of trunk	Peroneal.
Radial	Musculo-cutaneous.
Posterior interosseous	Anterior tibial.

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[1] According to Eisler, the femoral nerve is not exclusively dorsal, but contains both ventral and dorsal elements. The ventral part comprises the internal cutaneous nerve, the branch to the pectineus, and the saphenous nerve. Instead of occupying a ventral position at their origin, however, these branches are placed on the mesial side of the trunk, in consequence of a torsion, amounting to about 90°, which is to be recognised in the bundles of the nerve between the lumbar plexus and Poupart's ligament, and which is probably associated with the inward rotation of the limb during development.

UPPER LIMB. *Ventral branches.*	LOWER LIMB. *Ventral branches.*
N. to subclavius	Obturator.
Anterior thoracics	N. to quadratus femoris.
N. to coraco-brachialis	N. to obturator internus.
Musculo-cutaneous.	
Muscular part	Branches of tibial in thigh.
Cutaneous part	Cutaneous of obturator.
Median	Tibial: Mesial plantar.
Ulnar	Tibial: Lateral plantar.
Internal cutaneous Small internal cutaneous Intercosto-brachial	Posterior cutaneous: inner part of femoral division.

Recurrent or meningeal divisions.—These are presumably afferent nerves, and are said to be furnished by all the spinal nerves (p. 56).

Visceral or sympathetic divisions.—These are the white rami communicantes of the sympathetic system, in connexion with which their arrangement will be described (p. 149). They are absent in the cervical region, as well as from the lower two or three lumbar, first sacral, last sacral, and coccygeal nerves. The grey rami communicantes, as has already been explained, are not branches of the spinal nerves, but are given off by the sympathetic to the latter.

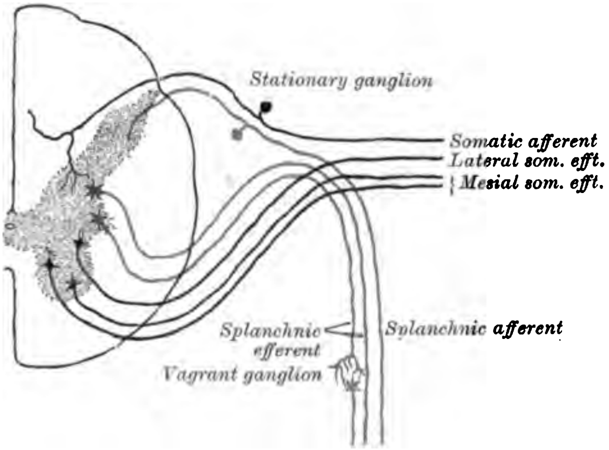

FIG. 74.—SCHEME OF THE HYPOTHETICAL CONSTRUCTION OF A SEGMENTAL NERVE. (Based mainly on Gaskell's classification of the component fibres.) (G. D. Thane.)

Ganglia.—The ganglia found in connexion with the peripheral nerves fall into two groups, which differ in their structure and position. To the first group belong the *spinal ganglia* on the dorsal roots of the spinal nerves, which contain unipolar nerve-cells. The other group includes the various *sympathetic ganglia*, the cells of which are multipolar. Both groups have a common origin, their nerve-cells being derived from the neural crest of the embryo (see Embryology, p. 98, and Neurology, Part I.). The spinal ganglia undergo but little change in position in the course of development, and are always placed on the dorsal roots of the nerves at or near their aperture of exit from the spinal canal, whence they have been named *stationary ganglia* by Gaskell. The neuroblasts which form the nerve-cells of the sympathetic ganglia, however, make their way along the spinal nerves and their visceral offsets into the ventral portion of the body, and there become collected into groups which give rise to the various sympathetic ganglia—the *splanchnic* or *vagrant ganglia* of Gaskell. It is probable that all the ganglia of the sympathetic arise in this way, but they have as yet been fully traced only in the case of the heart. The mode of development of the ganglia in the myenteric plexuses of the alimentary canal has not been observed.

Components of the spinal nerves.—A typical segmental spinal nerve comprises—(1) *somatic efferent fibres* distributed to skeletal muscles; (2) *splanchnic efferent* or *sympathetic fibres* passing through the sympathetic system, where many if not all are interrupted by the nerve-cells of the ganglia, to the visceral muscles and other unstriped muscles of the body, as well as to the glandular organs; (3) *somatic afferent fibres* supplying the skin and other parts of the body-wall with sensory nerves; and (4) *splanchnic afferent fibres* furnished to the viscera. The somatic efferent fibres and the greater part, if not the whole, of the splanchnic efferent fibres constitute the ventral root of the nerve; while the somatic afferent fibres run in the dorsal root, being connected with the cells of its ganglion, and the same is probably the case with the splanchnic afferent fibres. In the cervical region, in addition to the two roots of the cervical segmental nerves, there is also, arising separately from the cord, the accessory nerve, which, although reckoned with the cerebral nerves, is in greatest part of spinal origin. This belongs to a group, more developed among the cerebral nerves, which was designated by Gaskell *splanchnic non-ganglionated efferent*, but as it is distributed to skeletal muscles it is better termed *lateral somatic efferent*. The somatic efferent fibres in this region are therefore again divided into a *mesial set*, which arise from the cells of the fore-part and inner side of the ventral horn of the grey matter of the cord, and a *lateral set* derived from cells placed at the outer part of the ventral horn. It is uncertain whether the latter fibres are represented in the lower parts of the cord, but Gaskell places the phrenic nerve and the branches supplying the transversalis abdominis muscles in this group; if present, they also run in the ventral roots of the spinal nerves.

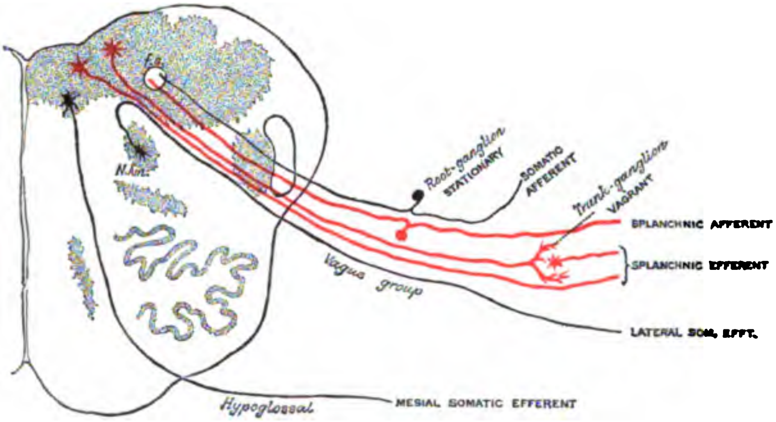

FIG. 75.—PLAN OF THE ARRANGEMENT OF THE COMPONENT FIBRES OF THE CEREBRAL NERVES IN THE BULB. (Based on Gaskell, with modifications.) (G. D. Thane.)

The somatic afferent fibres may be divided into (*a*) general cutaneous, (*b*) acoustico-lateral. The general cutaneous fibres are represented in all the spinal nerves by their dorsal roots. The acoustico-lateral fibres have in great part disappeared in mammals, but the acoustic nerve belongs to this system.

CEREBRAL NERVES.—The attempt to determine the morphological position of the cerebral nerves is beset with difficulties, and any classification that is based on the facts at present known with regard to their development, connexions, and functions can only be regarded as tentative. Assuming that they include the representatives of a series of segmental nerves, the arrangement is profoundly modified, on the one hand by the separation of the component portions of some of these nerves so as to form independent trunks, and on the other by the coalescence of elements belonging to different segments in a single stem. In many cases also parts of the typical segmental nerves are suppressed, either not being formed in the embryo, or disappearing more or less completely in the course of development. So great indeed is the change that it may be affirmed that no cerebral nerve, according to the usual enumeration, corresponds exactly to a single complete spinal segmental nerve, such as is met with in the thoracic region for example.

In considering the cerebral nerves from this point of view, the first two pairs are generally set aside as occupying an exceptional position, but evidence is not wanting that these have in some respects a similar origin to other sensory nerves. According to van Wijhe and Hoffmann, the olfactory nerves are developed at the anterior margin of the neuropore, at a spot where the floor of the neural groove or canal passes into the epidermis. This would correspond to the foremost part of the ganglion-groove of His, the forerunner of the neural or ganglion crest, at the place where it passes from one side to the other, following the margin of the medullary plate, and is not irreconcilable with the statement of Milnes Marshall that the olfactory nerves are derived from the foremost part of the neural crest. The optic nerve, including the retina, is developed as a hollow outgrowth of the neural tube, and Hoffmann states that in the elasmobranch the dorsal portions of the other cerebral nerves are formed in the same way, their ganglion-rudiments at first enclosing a cavity which is continuous with the medullary canal, so that the retina would correspond to a specially developed root-ganglion, and the optic nerve to a dorsal root. The relations of these nerves to the head-segments, however, have not been ascertained, and at all events for the present they cannot be grouped amongst the segmental nerves. In the following observations therefore only the ten nerves from the third to the twelfth inclusive are dealt with.

Components of the cerebral nerves.—Four of these nerves—namely, the twelfth, the sixth, the fourth, and the third—arise from large-celled nuclei forming a group which appears to be in series with the ventro-mesial cell-columns of the ventral cornu of the spinal cord. These nerves also, with the exception of the fourth, emerge from the axis in a line which forms a continuation of that of the ventral roots of the spinal nerves, and like those they consist mainly of large fibres (not so large in the hypoglossal, however, as in the others) which are distributed to voluntary muscles. In this group therefore are comprised the *mesial somatic efferent fibres* of the cerebral nerves.[1]

It has already been seen that in the upper cervical region the *lateral somatic efferent fibres* are separated from the ventral roots, and form the accessory nerve, which arises from the outer group of cells of the ventral horn. Proceeding upwards in the brain-stem, the following nuclei form a lateral series from which the fibres of this group arise—the bulbar portion of the accessory nucleus in part, the vago-glossopharyngeal nucleus (nucleus ambiguus), the facial nucleus, and the motor nuclei of the fifth nerve. The cells of the facial and vago-glossopharyngeal nuclei are of moderate size, but those of the motor nuclei of the fifth and accessory are larger. The fibres arising from these nuclei are mostly of medium size, but the spinal part of the accessory consists of large fibres. This group of fibres, with the possible exception of the spinal part of the accessory, supplies branchial muscles.

Splanchnic efferent fibres, characterised by their small size, are present in the bulbar portion of the accessory nerve, in the vagus nerve of which they form a large part, in the glossopharyngeal nerve (small superficial petrosal branch), in the facial nerve (the secretory fibres of the chorda tympani), and in the third nerve (ciliary portion). The origin of the splanchnic efferent fibres in the spinal cord has not been determined, but in the brain-stem there are special nuclei from which the fibres of this group arise. These are the bulbar portion of the accessory nucleus (in part), the small-celled vago-glossopharyngeal nucleus, from which not only the splanchnic efferent fibres of the vagus and glossopharyngeal proceed, but according to Duval also those of the facial, and the groups of smaller cells at the upper end of the oculomotor nucleus (see Part I. of this volume, p. 207).

Somatic afferent fibres constitute the greater part of the large root of the fifth nerve and the acoustic nerve; and a small group of these fibres occurs also in the vagus, composing its auricular branch. *Splanchnic afferent fibres* are contained in the facial (great superficial petrosal and taste-fibres of chorda tympani), glossopharyngeal, and vagus nerves, probably also in the sensory part of the fifth nerve. With regard to the central connexions of these fibres, it is to be remarked that many of them descend in the bulb and upper part of the spinal cord, forming the 'descending sensory roots'—the funiculus solitarius for the vagus and glossopharyngeal, perhaps also for the portio intermedia, and the bulbar root of the fifth nerve. A great number of the fibres enter the acoustic nuclei, the sensory nucleus of the fifth nerve, and the substantia gelatinosa, which may be looked upon as derivatives of the dorsal horn of the grey substance of the cord, just as the nerves at their attachment to the brain-stem form a series continuing the line of the dorsal roots. The afferent fibres, both somatic and splanchnic, are offsets of the cells of stationary ganglia and grow thence into the cerebrospinal axis. The component fibres of the several cerebral nerves are shown in the table on page 124.

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[1] According to Hatschek, there are also ventral roots to the glossopharyngeal and vagus nerves in Ammocœtes, and the same have been described in the embryo of man and the rabbit by Zimmermann.

TABLE SHOWING THE COMPONENTS OF THE CEREBRAL NERVES FROM THE THIRD TO THE TWELFTH.

Cerebral nerve.	Medial somatic efferent.	Lateral somatic efferent.	Splanchnic efferent.	Splanchnic afferent.	Somatic afferent.
Third	To orbital muscles.	—	Ciliary to ciliary muscle and circular fibres of iris	—	—
Fourth	To obliquus superior.	—	—	—	—
Fifth	—	Motor root.	?	Sensory	root.
Sixth	To rectus externus.	—	—	—	—
Seventh	—	Motor root.	Chorda tympani, fibres to submaxillary ganglion (secretory).	Chorda tympani (taste-fibres) and large superficial petrosal nerve.	—
Eighth	—	—	—	—	Acoustic.
Ninth	—	To stylopharyngeus.	Small superficial petrosal, to otic ganglion (secretory).	From tongue and pharynx, including taste-fibres.	—
Tenth	—	To laryngeal muscles?	To unstriped muscle of alimentary canal, air-passages, &c.	From alimentary canal, air-passages, &c.; cardiac depressor fibres.	Auricular.
Eleventh	—	To sternomastoid and trapezius; to laryngeal muscles?	To palatine and pharyngeal muscles; cardiac inhibitory fibres.	—	—
Twelfth	To tongue-muscles.	—	—	—	—

Ganglia.—The ganglia in connexion with cerebral nerves also fall into the two groups, stationary and vagrant, which have been characterised in dealing with the spinal nerves (p. 121).

Stationary ganglia necessarily occur only on those nerves which contain afferent fibres. They are the semilunar ganglion on the large root of the fifth nerve, the geniculate ganglion on the pars intermedia of the facial, the cochlear and vestibular ganglia on the acoustic nerve, the jugular and petrosal ganglia of the glossopharyngeal nerve, and the upper ganglion (possibly also the lower) of the vagus nerve. The nerve-cells are unipolar, like those of the spinal ganglia, in all of these except the cochlear and vestibular ganglia, in which the cells retain a bipolar form. There are also found upon the roots of the third, fourth, motor part of the fifth, and seventh nerves traces of a structure which was regarded by Gaskell as indicative of the former existence of stationary ganglia and afferent fibres belonging to those nerves. In some animals, and rarely in man, there is a gangliated dorsal root to the hypoglossal nerve.

The *vagrant ganglia* in connexion with the cerebral nerves include four ganglia usually associated with the fifth nerve—namely, the ciliary, sphenopalatine, submaxillary, and otic—all of which are of sympathetic type, containing multipolar nerve-cells, and, according to Gaskell, also the lower ganglion of the vagus, the cells of which are, however, of the spinal type. The ciliary, sphenopalatine, and otic ganglia may be developed as offsets of the semilunar ganglion, and the same is probably the case with the submaxillary ganglion, but they receive splanchnic efferent fibres, with which they form connexions from other sources—the ciliary ganglion from the third nerve, the submaxillary ganglion from the facial through the chorda tympani, and the otic ganglion from the glossopharyngeal. The condition in the last three cases resembles that where a given ganglion of the sympathetic cord receives efferent fibres from spinal nerves at different levels.

Segmentation.—It has been shown in some of the lower vertebrates, especially elasmobranchs, that at least nine segments are included in the constitution of the head, and it is probable that the number is not less in the higher vertebrates, although it may be that the segments have not the same morphological value in all cases, since there is reason for believing that only six of these belonged primitively to the head, while three or more, originally spinal, have also become incorporated in the head in later stages of phylogenetic development. Assuming provisionally, however, that the nerves of nine segments are represented more or less completely in the ten cerebral nerves, there is still much uncertainty as to the manner in which some of these nerves are to be allotted to the several segments. It is also to be observed that, as in the case of the spinal nerves, the segmentation which is to be recognised in the central grey matter does not always correspond to the segmentation represented in the nerve-trunks, since fibres which arise from what appears to be a single segmental nucleus may pass out in nerves at different levels, and, conversely, a single nerve may contain fibres derived from the nuclei of more than one segment.

The third nerve belongs to the first head-segment. It includes a large-fibred mesial somatic efferent part, distributed to most of the orbital muscles, and a small-fibred splanchnic efferent part passing to the ciliary ganglion. The ophthalmic division of the fifth appears to be the afferent nerve of this segment. In the elasmobranch Hoffmann finds that the 'ramus ophthalmicus profundus,' which corresponds to the nasociliary nerve of man (J. C. Ewart), is developed independently of the rest of the fifth nerve, and in close relation to the first somite. Gaskell considers, however, that the afferent fibres of the first segmental nerve, with their stationary ganglion, have undergone degeneration, and are now represented only by a vestigial structure in the roots of the third nerve; and his view receives support from the observation of Martin that in the early embryo of the cat the third nerve is provided with a dorsal root, which subsequently disappears.[1]

The fourth nerve, supplying the superior oblique muscle, is the mesial somatic part of the second segmental nerve. The fifth nerve, excluding the ophthalmic division, also belongs to this segment (Hoffmann), of which the motor root of the fifth will therefore form the lateral somatic efferent nerve, while the maxillary and mandibular portions of the sensory root will be the afferent nerve.

The third segmental nerve includes the sixth, seventh, and eighth cerebral nerves. The sixth is the mesial, and the motor part of the facial the lateral somatic efferent portion. In the sensory portion of the seventh are comprised splanchnic efferent fibres to the submaxillary ganglion and splanchnic afferent fibres through the chorda tympani and the great superficial petrosal. The somatic afferent part is the acoustic, with the acoustic ganglia, the resemblance of which to the dorsal root of a spinal nerve has already been pointed out.

The fourth segmental nerve, according to Hoffmann, is suppressed. A rudiment is present in the early embryo of the elasmobranch, but it afterwards aborts.

The nerve of the fifth segment is the glossopharyngeal. In this, mesial efferent and afferent somatic fibres are altogether wanting. Lateral somatic efferent fibres are present in the branch to the stylopharyngeus, and probably arise from the accessory vago-glossopharyngeal nucleus. Splanchnic efferent fibres run in the small superficial petrosal nerve to the otic ganglion. The chief part of the nerve, however, is composed of splanchnic afferent fibres, which enter the funiculus solitarius.

The sixth and seventh segmental nerves are united in the vagus (Hoffmann), which contains fibres of all groups except mesial somatic efferent. The latter fibres of the seventh segment may be included in the hypoglossal nerve, which is composed of the mesial somatic efferent parts of the last three or more cephalic (originally spinal) segmental nerves. Otherwise, these segmental nerves are only represented (doubtfully) by the oral fibres of the facial, which are said to arise from the hypoglossal nucleus (lateral somatic efferent), and by the bulbar part of the accessory (lateral somatic efferent and splanchnic efferent), except in those cases in which the hypoglossal nerve is provided with a gangliated dorsal root.

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[1] What appears to be a gangliated dorsal root to the oculomotor nerve has also been described by Kupffer in Ammocœtes, and by Froriep in Torpedo.

The arrangement sketched out above is summed up in the annexed table:

TABLE OF THE SEGMENTAL NERVES OF THE HEAD.

SEGMENTAL NERVE.	Mesial somatic efferent.	Lateral somatic efferent.	Splanchnic efferent.	Vagrant ganglia.	Splanchnic afferent.	Somatic afferent.	Stationary ganglia.
FIRST	Oculomotor.	Ocular facial?	Ciliary.	Ciliary.	Ophthalmic.		Semilunar.
SECOND	Trochlear.	Fifth, small root.	—	Spheno-palatine. Otic. Submaxillary?	Maxillary and mandibular.		
THIRD	Abducens.	Facial, motor root.	Facial, secretory fibres.	—	Facial sensory fibres.	Acoustic.	Acoustic and geniculate.
FOURTH	—	—	—	—	—	—	—
FIFTH	—	Glossopharyngeal, fibres from nucleus ambiguus.	Small superficial petrosal.	—	Glossopharyngeal, fibres to funiculus solitarius.	—	Jugular and petrosal.
SIXTH	—	Vagus, fibres from nucleus ambiguus.	Vagus, fibres from small-celled nucleus.	Trunk-ganglion.	Vagus, fibres to funiculus solitarius.	Auricular.	Root-ganglion.
SEVENTH	Hypoglossal.						
EIGHTH		Oral facial? Bulbar part of accessory.	Bulbar part of accessory.	—	—	Dorsal root of hypoglossal,	with ganglion.
NINTH							

Course and distribution.—While it is obvious that in the distribution of the cerebral nerves the segmental arrangement, if it ever existed, has been in many cases greatly modified, there are certain striking relations between the course and distribution of some of these nerves and the developmental subdivisions of the head.

The distribution of the third, fourth, and sixth nerves to the muscles of the first three somites has already been pointed out. The naso-ciliary branch of the ophthalmic division of the fifth is the nerve of the fronto-nasal process. The mandibular is the nerve of the mandibular arch, its motor root supplying the muscles of that arch and its sensory part extending by its splanchnic lingual branch into the part of the tongue which is formed from the tuberculum impar in the concavity of the arch. The maxillary nerve is the offset furnished by the more primitive mandibular nerve to the maxillary process. The three divisions of the fifth supply the skin externally, and the mucous membrane internally, of their respective portions of the face; and they send dorsal branches—supra-orbital and supra-trochlear, zygomatic, and auriculo-temporal—to ramify over the neural cavity in the same way as the dorsal divisions of the spinal nerves, with the cutaneous area of which they are continuous on the scalp.

The facial is the nerve of the hyoid arch, supplying the muscles of that arch—stapedius, posterior belly of digastric, and stylohyoid—and the system of cutaneous muscles which, according to Rabl, take their origin in that arch.

The glossopharyngeal is the nerve of the third cephalic visceral (first branchial) arch, in which it runs to the root of the tongue, but its lingual distribution extends considerably beyond the part which is formed from that arch. It also supplies the muscle of the third arch—the stylopharyngeus.

The vagus is a complex nerve. Its auricular branch, somatic in nature, is the diminished representative of a largely developed somatic portion in fishes, known as the 'lateral branch.' The superior laryngeal is the nerve of the fourth visceral (second branchial) arch, and the recurrent laryngeal of the fifth (third branchial) arch, the latter being drawn down so as to acquire its recurrent character by the shifting of the arteries during development. The remaining portion of the vagus extends far beyond the limits of the head, and supplies nearly the whole of the alimentary canal with its derivatives, and other abdominal organs, the greater part of which, it is to be noted, are developed from the foregut or cephalic segment of the enteric cavity. The bulbar part of the accessory in its distribution cannot be separated from the vagus; and the spinal portion of the same nerve is not morphologically cerebral, but entirely spinal both in origin and distribution.

Lastly, the hypoglossal nerve, also spinal originally, is distributed to tongue-muscles, which are also foreign to the head, being probably derived from the longitudinal system of the ventral muscles of the trunk. It is thus in series with the upper cervical nerves supplying the muscles of the front of the neck, and the connexion that is formed between the hypoglossal and these nerves, giving rise to the ansa cervicalis, &c., may be regarded as representing a prolongation of the cervical plexus.

DISTRIBUTION OF AFFERENT FIBRES OF THE CEREBROSPINAL NERVES, WITH A SUMMARY OF THE AREAS SUPPLIED.

1. **In the head.**—The skin of the head is supplied by the fifth and tenth cerebral nerves and by the second and third cervical spinal nerves. At an early period in embryonic life the general distribution of the fifth nerve is outlined by the growth from the semilunar ganglion of three trunks into the fronto-nasal, maxillary, and mandibular processes. This distribution persists throughout life, but undergoes some modifications mainly owing to the great expansion of the cranial roof and to changes in the relative growth of the face and neck.

Our knowledge of the cutaneous distribution of the fifth nerve has been rendered more exact in recent years by the dissections of Frohse[1] and Zander,[2] and especially by the study of cases of complete extirpation of the semilunar ganglion by Krause,[3] Cushing,[4] and others. Cushing found that after the semilunar ganglion had been completely removed there were two lines which could be mapped out at the posterior boundary of the trigeminal area (see fig. 76). 'The more anterior of these lines bounds the area within which anæsthesia is complete to all forms of sensation; the more posterior outlines the area within which the anæsthesia, though complete to thermic, dolorous, and tactical stimuli, nevertheless is not absolute, since perception for painful stimuli remains, the impulses being interpreted, however, not as pain, but as pressure or contact.' The posterior line varied somewhat in different patients both above and below the ear, but it always extended backwards to the anterior wall of the external auditory meatus. From a comparison of the posterior limit of the trigeminal sensory area with the contiguous boundary-line of the cervical nerves, as ascertained after these nerves were divided for the removal of cervical glands, &c., Cushing considers the overlap of the trigeminal and cervical fields is not nearly as marked in man as Sherrington's results on monkeys might lead one to suppose, and he believes that this applies also to the boundaries between the three divisions of the fifth nerve.

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[1] Die oberflächlichen Nerven des Kopfes, 1895.

[2] 'Beiträge zur Kenntniss der Hautnerven des Kopfes,' Anatomische Hefte, ix. 1897.

[3] Die Neuralgie des Trigeminus nebst der Anatomie und Physiologie des Nerven, 1896.

[4] 'The Sensory Distribution of the Fifth Cranial Nerve,' Bulletin of the Johns Hopkins Hospital, xv. 1904.

The ophthalmic division supplies branches to the forehead, upper eyelid, dorsum of the nose, and the eyeball. The maxillary division supplies the greater part of the cheek, the side of the nose, upper lip, lower eyelid, and the region behind the eye over the fore-part of the temporal fossa. The mandibular division supplies the chin and lower lip, the hinder part of the cheek, the fore and upper parts of the pinna of the ear on its outer side, and the integument in front of the ear and upwards on the side of the head.

According to Frohse[1] there is considerable variation in the relative extent of the skin supplied by the second and third divisions of the fifth, this being mainly dependent upon the varying size of the facial branches of the auriculo-temporal nerve. The auricular branch of the vagus nerve also is distributed over a small area on the concha of the pinna, and the posterior part of the external auditory meatus and the membrana tympani. The branches to the head from the cervical nerves are the *great occipital*, *third occipital*, *great auricular*, and *small occipital*. The skin of the scalp, behind a vertical line prolonged downwards through the external auditory meatus, is mainly supplied by the great occipital branch of the dorsal division of the second spinal nerve, but above the occipital protuberance there is also distributed the branch from the dorsal division of the third spinal nerve; and in front of the area of these occipital nerves is a space supplied by ventral divisions of spinal nerves—viz. the back of the pinna of the ear, the greater part of its outer surface, and the skin over the parotid gland and masseter muscle, which are supplied by the great auricular nerve (2, 3 *c*); while between the area of this nerve and the great occipital the small occipital nerve (2, 3 *c*) reaches the scalp, and sometimes sends a branch to the upper part of the pinna.

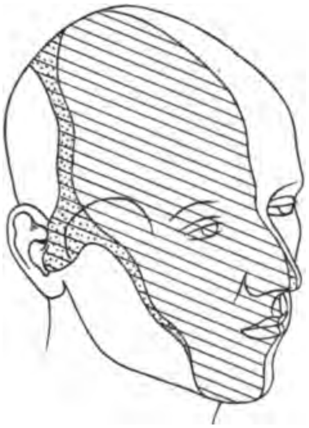

FIG. 76.—DIAGRAM OF THE AREA OF LOSS OF SENSIBILITY AFTER COMPLETE REMOVAL OF THE SEMILUNAR GANGLION OF THE TRIGEMINAL NERVE. THE PURELY STRIPED AREA REPRESENTS THE FIELD OF COMPLETE ANÆSTHESIA; IN THE NARROW PUNCTATED AND STRIPED AREA BEHIND THIS THE ANÆSTHESIA WAS INCOMPLETE. (Cushing.)

Cavities of the head.—The mucous membrane of the *nasal fossa* is supplied by the olfactory nerves and the first and second divisions of the fifth nerve. The ramifications of the olfactory nerves are restricted to the small olfactory region at the highest part of the cavity; the naso-ciliary branch of the ophthalmic division of the fifth nerve supplies the anterior portion of the lining membrane; and the maxillary serves all the remainder. The *frontal sinus* is supplied by the naso-ciliary nerve, the *ethmoidal cells* and *sphenoidal sinus* by the naso-ciliary and maxillary, and the *maxillary antrum* by the maxillary nerve.

In the *mouth*, the upper lip, the teeth of the upper jaw with the gum, and the mucous membrane of the hard palate, are supplied by the maxillary nerve. The lower lip and the inner surface of the cheek, the lower teeth and the gum, and the greater part of the tongue in front of the anterior pillars of the fauces, together with the mucous membrane of the alveolo-lingual sulcus, are supplied by the mandibular nerve. The taste-fibres of the fore-part of the tongue run in the chorda tympani; and the root of the tongue is supplied by the glosso-pharyngeal nerve. The *soft palate* receives branches from the maxillary, facial, and glosso-pharyngeal nerves. The mucous membrane of the *pharynx* in its upper part, including the mouth of the Eustachian tube, receives twigs of the maxillary nerve; in the rest of its extent it is supplied by the glossopharyngeal and vagus nerves, mainly through the pharyngeal plexus, but in the neighbourhood of the superior aperture of the larynx it receives filaments of the superior laryngeal nerve. The *larynx* is supplied mostly by the superior laryngeal nerve, but in its lowest part it receives fibres from the recurrent laryngeal, which also supplies the *trachea.* The sensory nerves of the *œsophagus* are probably derived from the vagus.

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[1] Die oberflächlichen Nerven des Kopfes, Plate III.

The mucous lining of the *tympanic cavity* and *Eustachian tube* are supplied by the glossopharyngeal nerve, while to the *mastoid cells* filaments pass from the same source, as well as

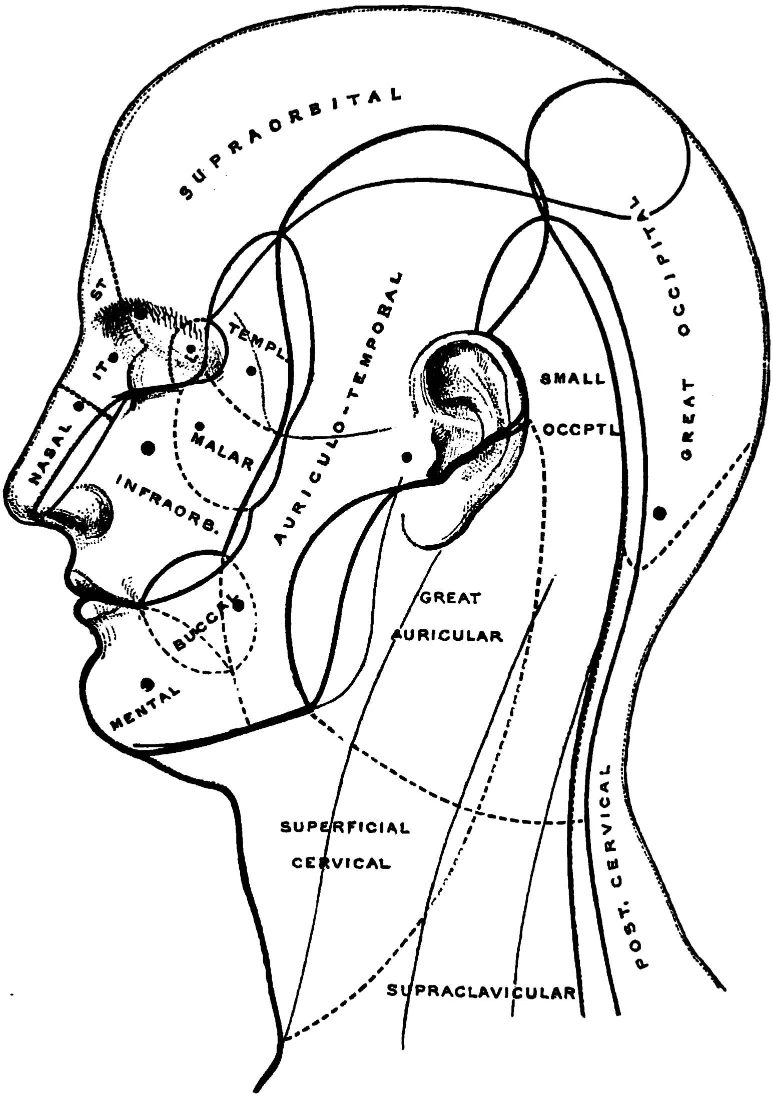
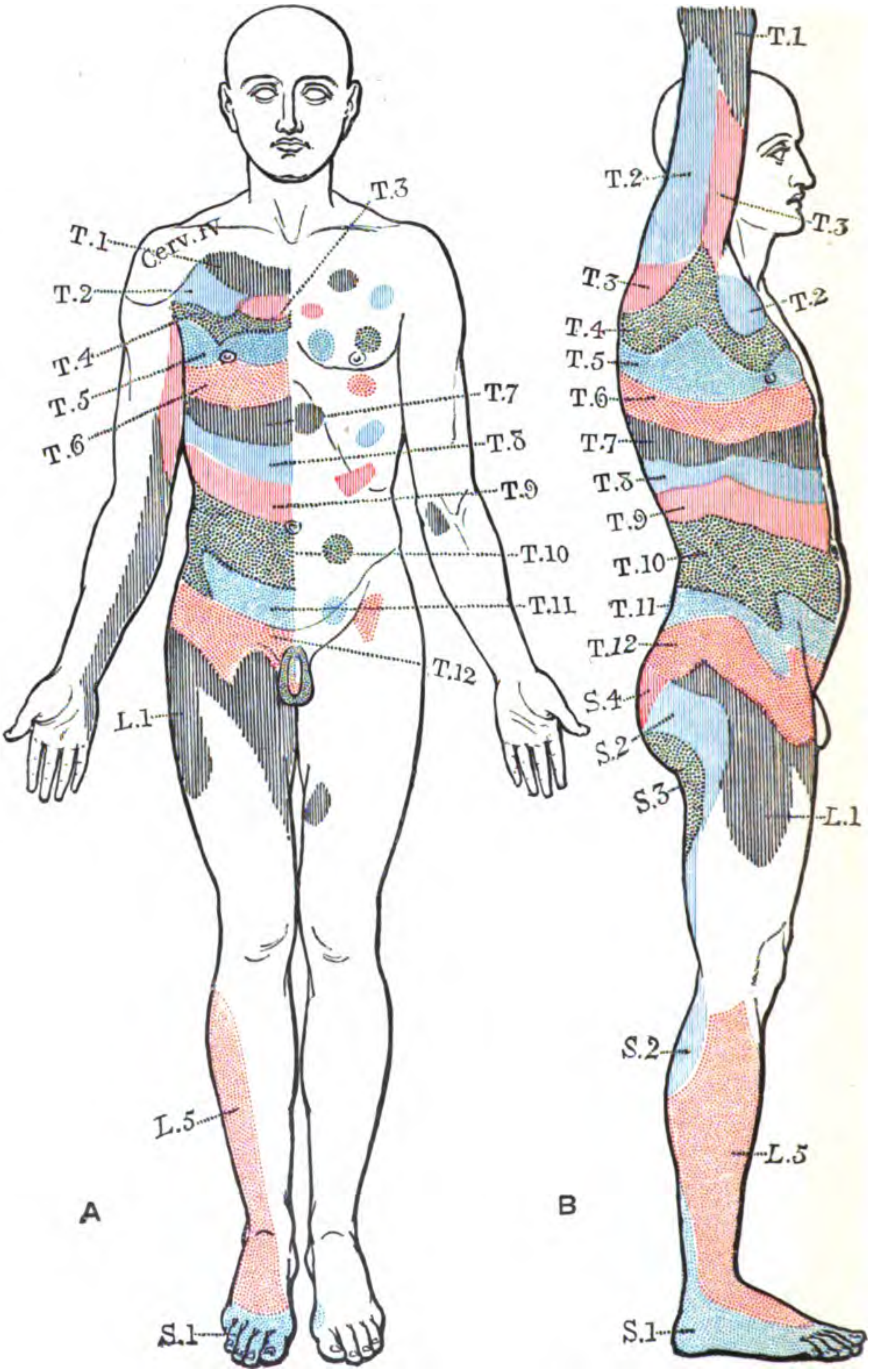


FIG. 77.—CUTANEOUS AREAS OF THE NERVES OF THE HEAD AND NECK. (G. D. Thane.)

The areas supplied by the branches of the first division of the fifth are enclosed by black lines; those supplied by the second division of the fifth and by branches of the cervical plexus by red lines; and those supplied by the third division of the fifth and by the dorsal primary divisions of the cervical nerves by blue lines. S T, supratrochlear, I T, infratrochlear, and L, lacrymal branches of the first division of the fifth. The hinder part of the cheek, on which the word 'auriculo' is placed, receives fibres of the auriculo-temporal nerve through the communication with the facial. The black spots denote the points at which the respective nerves become superficial.

In this and similar figures the overlapping of adjacent nerves is indicated, so that along the boundary of each area there is a region which is supplied by the two nerves. It is, however, to be remarked that, owing to the difficulty of determining anatomically the precise extent of skin supplied by a branch of nerve, and the great degree of individual variability in this respect, neither the extent of the several areas nor the degree of overlapping is to be regarded otherwise than as an approximate representation of what appears to be the average condition.


T.3
T.1
Cerv. IV
T.2
T.4
T.5
T.6
T.7
T.8
T.9
T.10
T.11
T.12
L.1
L.5
S.1
A
T.1
T.2
T.3
T.3
T.2
T.4
T.5
T.6
T.7
T.8
T.9
T.10
T.11
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S.4
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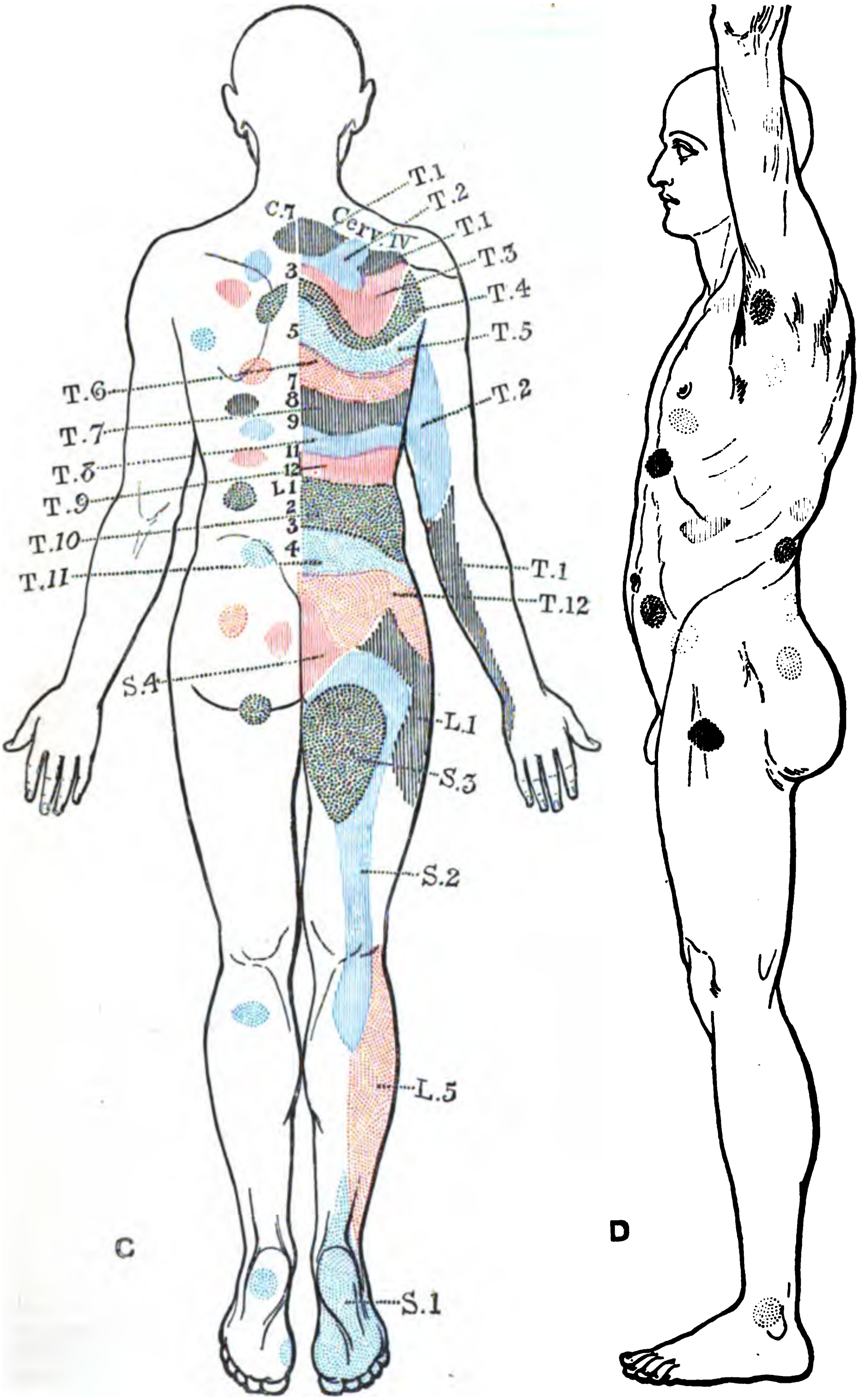
S.3
L.1
S.2
L.5
S.1
B

Fig. 78.—(For explanation, see p. 182.)


T.1
C.7
T.2
Cerv. IV
T.1
T.3
3
T.4
5
T.5
T.6
7
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8
T.7
9
11
T.8
12
L1
T.9
2
3
T.10
4
T.1
T.11
T.12
S.4
L.1
S.3
S.2
L.5
S.1
C
D

Fig. 78.—(For explanation, see p. 132.)

from the mandibular nerve (Luschka). The outer surface of the *tympanic membrane*, like the skin of the external auditory meatus generally, is supplied by the auriculo-temporal of the fifth and the auricular branch of the vagus nerves.

In the *cranial cavity* the dura mater is almost entirely supplied by branches from the three divisions of the fifth, but it also receives twigs from the vagus.

2. **In the trunk.**—The manner in which the afferent fibres are distributed to the skin has been greatly elucidated by the experimental investigations of Sherrington,[1] the dissections of Herringham,[2] Paterson,[3] and Bolk,[4] and the clinical and pathological observations of Ross,[5] Thorburn,[6] Head,[7] Mackenzie,[8] and others.

From these observations it has now been clearly demonstrated that the general plan on which the spinal nerves are distributed to the skin is in the form of transverse or oblique zones (spinal dermatomes) extending from the mid-dorsal to the mid-ventral line. In certain regions, however, the position of the zones has been greatly modified by development-changes, such as the growth of the limbs and the suppression of the tail. The most typical illustrations of this zonular distribution are found in the trunk between the attachments of the upper and lower limbs – viz. from the second thoracic to the first lumbar nerve, although even here most of them have undergone some modification in their form or direction. The first thoracic does not give any branches to the skin of the trunk except over a small area on the dorsal surface near the spine. The second thoracic forms a narrow transverse zone on the anterior aspect of the chest a little below the clavicle, and the adjacent area above is supplied by the fourth cervical, the five intervening spinal nerves having been drawn outwards for the supply of the upper limb. On the outer side of the trunk the second thoracic zone extends along the inner side of the arm, but according to Head's diagram it is not continuous with the corresponding

FIG. 78.—SEGMENTAL CUTANEOUS AREAS FROM THE FIRST THORACIC TO THE FOURTH SACRAL, AS DETERMINED BY CLINICAL AND PATHOLOGICAL OBSERVATIONS IN MAN. (Head.)

On the right side of the figures the areas are marked by different colours and modes of shading; on the left side the 'maximum spots' (seat of most marked tenderness and pain) of the areas are shown. The several thoracic, lumbar, and sacral areas are indicated each by the initial letter followed by a number. In C, C 7 is the seventh cervical spine, 8 to 12 are the corresponding thoracic spines, and L 1 to 4 are lumbar spines.

Figs. 78, 79, and 80 represent the 'segmental areas' of the skin over the trunk and limbs as determined by Head from clinical observations. These areas are, however, not the regions supplied by the respective dorsal spinal nerve-roots, but represent rather the parts of the skin in connexion with the segments of the grey matter of the spinal cord by means of fibres subserving the sensations of pain, heat, and cold, but not touch. They differ strikingly from the areas of the dorsal nerve-roots in not overlapping, except to a small extent in the neck and upper limbs, whereas the root-areas overlap so much that there is no loss of tactile sensation after division of a single dorsal root (Sherrington, Head). It may also be pointed out that the areas as designated by Head do not always agree with the distribution of the corresponding nerves as determined anatomically. Thus, the area marked T 3 on the inner side of the arm corresponds rather to the brachial distribution of the second thoracic nerve through its intercosto-brachial branch and the communication with the lesser internal cutaneous nerve, while the third thoracic nerve does not usually contribute largely to the supply of the arm. Similarly, the areas marked T 11, T 12, and L 1 would seem on anatomical grounds, as well as from observations in cases of injury, as shown by Thorburn, to correspond more nearly to the twelfth thoracic and first and second lumbar nerves. It is therefore possible that, while the general arrangement and distribution of the segmental areas, as well as their visceral associations, have been in principle correctly recognised by Head, some modifications in the details of limitation and enumeration of these areas may be rendered necessary by more extended observations.

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[1] C. S. Sherrington, 'Experiments in Examination of the Peripheral Distribution of the Fibres of the Posterior Roots of some Spinal Nerves,' Proc. Roy. Soc. lii. 1892, and Phil. Trans. 1893.

[2] W. P. Herringham, 'The Minute Anatomy of the Brachial Plexus,' Proc. Roy. Soc. xli. 1886.

[3] A. M. Paterson, 'The Origin and Distribution of the Nerves to the Lower Limb,' Journ. of Anat. and Phys. xxviii. 1893–4; and 'A Discussion on some Points in the Distribution of the Spinal Nerves,' Journ. Anat. xxx. 1896.

[4] C. Bolk, 'Die Segmentaldifferenzirung des menschlichen Rumpfes und seiner Extremitäten,' Morph. Jahrbuch, xxvi., xxvii., xxviii.; R. Wichmann, Die Rückenmarknerven und ihre Segmentbezuge, 1900; Grosser u. Fröhlich, 'Beiträge zur Kenntniss der Dermatome der menschlichen Rumpfhaut,' Morph. Jahrbuch, xxx.

[5] J. Ross, 'On the Segmental Distribution of Sensory Disorders,' Brain, 1888; and in 'Studies in Anatomy,' the Owens College, 1891.

[6] W. Thorburn, 'A Contribution to the Surgery of the Spinal Cord,' 1889; 'The Sensory Distribution of Spinal Nerves,' Brain, part lxiii. 1893.

[7] H. Head, 'On Disturbances of Sensation, with especial reference to the Pain of Visceral Disease,' Brain, parts lxi. and lxii., 1893, and lxvii. 1894; and H. Head and A. W. Campbell, 'The Pathology of Herpes Zoster, and its bearing on Sensory Localisation,' Brain, xxiii. 1900.

[8] J. Mackenzie, 'Some Points bearing on the Association of Sensory Disorders and Visceral Disease,' Brain, part lxiii. 1893.

area on the dorsum of the trunk. The third thoracic zone sends down a small process internal to the nipple-line, and at the axilla reaches a considerable distance down the inner aspect of the arm. In the previous edition (1895) of this work Thane showed that this area corresponded to the distribution of the intercosto-brachial from the second thoracic; but Head still (1900) maintains the accuracy of his original figure. The fourth zone resembles the third in being

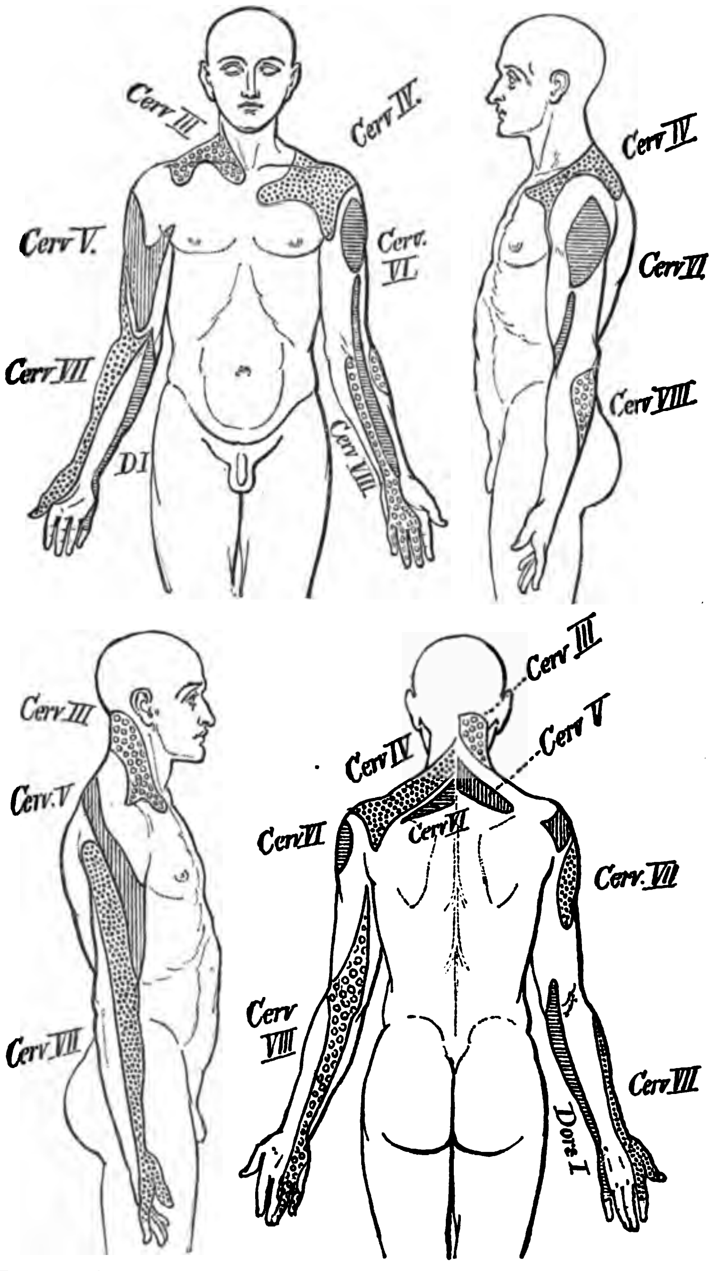
Cerv III
Cerv IV.
Cerv V.
Cerv. VI.
Cerv VII
DI
Cerv VIII
Cerv IV
Cerv VI
Cerv VIII
Cerv III
Cerv. V
Cerv VII
Cerv III
Cerv V
Cerv IV
Cerv VI
Cerv VI
Cerv. VII
Cerv VIII
Cerv VIII
Dors I

FIG. 79.—THE SEGMENTAL CUTANEOUS AREAS FROM THE THIRD CERVICAL TO THE FIRST THORACIC. (Head.)

interrupted at the axilla, but all the remaining thoracic nerves, and also the first lumbar, form continuous zones. The nipples lie partly in the fourth and partly in the fifth zone, and both these bands become modified in this region by the development of the mammary gland during pregnancy and lactation. The sixth zone maintains a nearly uniform size and transverse course. It begins opposite the seventh and eighth spines, passes round the chest just below the scapula, and over the eighth, seventh, and sixth intercostal spaces, to end at the fifth interspace. Below the sixth the zones incline obliquely downwards in their course from behind forwards, but near the mid-ventral line they curve upwards. According to both Head and Bolk, the umbilicus is between the ninth and tenth zones, but Thorburn places it in the lowest part of the tenth. Head represents the twelfth thoracic as being partly above and partly below Poupart's ligament, and the first lumbar as entirely below the abdominal wall. Thorburn and Thane consider that Head places these nearly a zone too low.

An examination of fig. 78 will show that, while the thoracic zones at the upper end of the series begin opposite their corresponding spinous processes, they soon cease to do so, and are found to start at gradually increasing distances from their processes. Thus the sixth zone begins opposite the seventh to the eighth spine, the ninth opposite the twelfth, and the twelfth starts as low as the fourth lumbar spine. The thoracic zones down to the sixth are nearly horizontal, and therefore do not correspond to the intercostal spaces and the main trunk of the intercostal nerves. In order to reach their zones the cutaneous branches of the dorsal primary divisions of the thoracic nerves descend between the longitudinal muscles of the back before piercing the superficial muscles to supply the skin. This obliquity is slight in the case of the upper nerves, but gradually increases from above downwards, so that the last thoracic only reaches the skin near the iliac crest (Thane) (fig. 42).

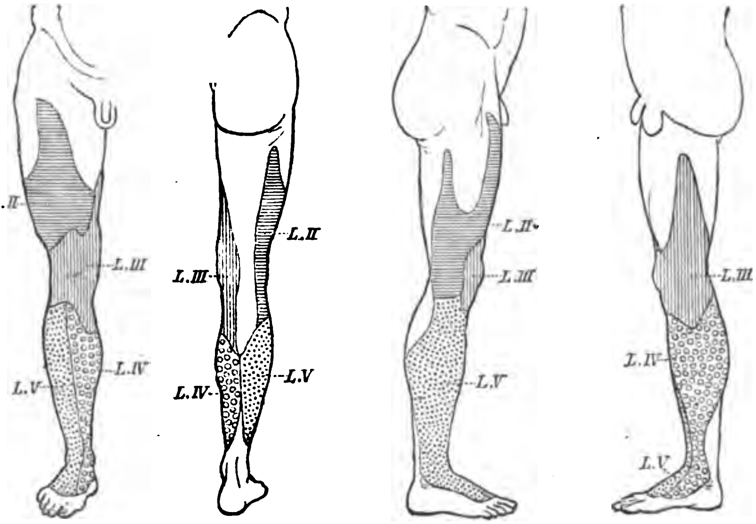

FIG. 80.—THE SEGMENTAL CUTANEOUS AREAS FROM THE SECOND TO THE FIFTH LUMBAR. (Head.)

The second lumbar area is marked with cross lines, the third with vertical lines, the fourth with circles, and the fifth with dots.

The upper thoracic zones down to the sixth are practically horizontal, and in these regions the anterior and posterior branches of the lateral cutaneous nerves do not correspond in direction to the intercostal nerves, but take a nearly horizontal course.

Sherrington found in the macaque the overlap to be so great that after the division of a single dorsal spinal root there was no loss of tactile sensation. The amount of overlap in the human subject has not been satisfactorily determined, but it is probably not so marked as in the macaque. According to Head, the adjacent areas in man freely interdigitate.

The typical zonular skin-areas seen in the part of the trunk innervated by the thoracic nerves are not so evident in the neck, as the great expansion of the cranium has drawn some of the branches of the upper cervical nerves a considerable distance on to the scalp and face, while the development of the upper limb has produced a still greater displacement of the lower cervical segmental skin-areas. The first cervical nerve does not apparently give any branches to the skin, and the lower four cervical nerves are almost entirely confined in their distribution to the upper limb, so that the skin of the neck depends for its supply upon the second, third, and fourth cervical nerves. The exact area of distribution of each of these spinal nerves has not been satisfactorily determined, as several of the main branches of distribution arise from two spinal nerves: thus the great auricular, the superficial cervical, and sometimes also the small occipital, come from the second and third cervical, and the supraclavicular branches from the third and fourth cervical. It is probable, however, that they supply three oblique and irregular areas (see fig. 81). The second cervical meets the trigeminal area on the scalp, pinna, and face, and the fourth extends downwards over the clavicle and shoulder to join the first and second thoracic areas.

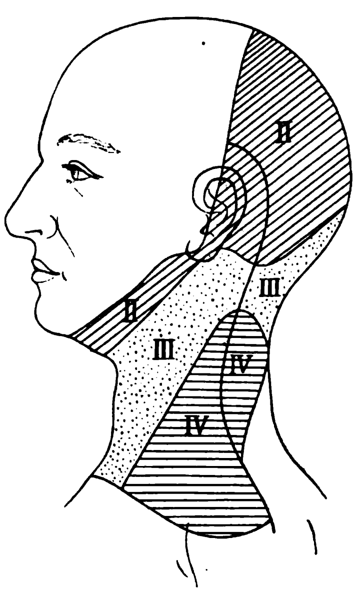

Fig. 81.—Area of skin supplied by the second, third, and fourth cervical nerves. (Bolk.)

The line curving downwards behind the pinna separates the areas supplied by the dorsal and ventral divisions of the nerves.

3. **In the perineum and coccygeal region.**—This area is supplied by spinal nerves continuous with and postaxial to those supplying the lower limb. Owing to the atrophy of the tail in man, the area of distribution of these nerves is small, and the lowest nerves are so minute that their cutaneous distribution cannot be satisfactorily determined by dissection. On theoretical grounds, which have been confirmed by pathological observations, they may be assumed to supply a series of concentric areas (fig. 82), with the central one opposite the tip of the coccyx and supplied by the coccygeal pair of nerves.[1]

The *dorsal divisions of the spinal nerves* supply an area extending on the back from the vertex of the skull to the buttock. This area is narrow in the neck; it is expanded in the upper thoracic region, extending over the back of the scapula: in the lower thoracic and lumbar regions its extent may be marked by a line drawn from the lower angle of the scapula (the arm hanging against the side) to the middle of the iliac crest; and in the buttock its lower limit is indicated by a line from the tip of the coccyx to the great trochanter (see fig. 42, p. 58). The series of cutaneous branches is not continuous, there being gaps in the lower cervical and lower lumbar regions, corresponding to the middle parts of the brachial and lumbosacral plexuses; that is, those spinal nerves which contribute most largely to the supply of the limbs do not furnish cutaneous offsets to the trunk.

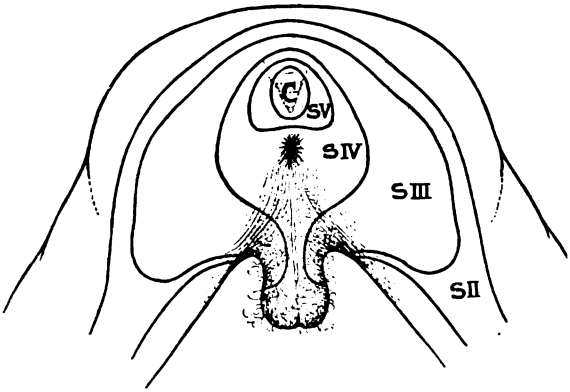

Fig. 82.—Diagram of the cutaneous areas supplied by the lower sacral and the coccygeal nerves. (Modified from Cushing.)

The *area supplied by the cervical plexus*, besides extending upwards, as already mentioned, on the lateral part of the skull, stretches over the front and sides of the neck, and the upper part of the shoulder and breast.

The *area of the ventral divisions of the thoracic and first lumbar nerves* meets superiorly with that of the cervical plexus, and posteriorly with that of the dorsal divisions of the thoracic and lumbar nerves. It passes down over the haunch and along by the outer part of Poupart's ligament, and includes part of the penis and scrotum, and a small portion of the integument of the thigh internal to the saphenous opening. This extensive area may be subdivided by a line passing through the nipple downwards to the centre of Poupart's ligament into a mesial region supplied by the anterior cutaneous branches of the nerves, and a larger lateral region supplied by the lateral cutaneous branches. In the former region the skin over the ensiform process is supplied by the sixth and seventh thoracic nerves, and that around the umbilicus usually by the tenth thoracic nerve.

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[1] See H. Cushing, 'Perineal Zoster, with Notes upon Cutaneous Segmentation Postaxial to the Lower Limb,' American Journal of the Medical Sciences, 1904.

The *root of the penis* on its dorsal aspect and a part of the *scrotum* anteriorly are supplied by the ilio-inguinal and genito-femoral nerves (1 *l*). The greater part of the *penis*, the lower and hinder parts of the *scrotum*, and the *perineum* are supplied by the pudendal nerve (2, 3, 4 *s*), the scrotum also receiving branches from the perineal branches of the posterior cutaneous of the thigh (2, 3 *s*). The branches to the penis are derived mainly from the second sacral nerve, to a less extent from the third; those to the scrotum and fore-part of the perineum chiefly from the third nerve, but in part also from the second; and those to the hinder part of the perineum from the third and fourth sacral nerves (Paterson).

4. **In the limbs.**—The limbs are developed as lateral outgrowths of the trunk, each limb being opposite a certain number of mesoblastic somites and having branches of the corresponding spinal nerves prolonged into it. Although these nerves become mingled in the plexuses, there is a similar principle to be recognised in their ultimate distribution, as in the trunk, the fibres derived from the several spinal nerves being supplied to definite continuous areas in positions which are readily explained by reference to the mode of development of the limb. Thus, the upper nerves are distributed along the pre-axial side of the limb, and the lower nerves along the postaxial side, while the intermediate nerves descend along the centre of the limb, and supply only the more distal parts (see fig. 83). The skin at the root of the limb is not supplied by offsets of the limb-plexus, but by branches of nerves which have been drawn out, as it were, with the skin of the adjoining part of the trunk during the development of the limb. The main trunks of the limb-plexuses divide into ventral and dorsal branches, which are distributed to the corresponding surfaces of the limbs.

The following rules have accordingly been formulated by Herringham from his observations on the nerves of the upper limb, and have been confirmed by Paterson for the lower limb:

A. *Of two spots on the skin, that which is nearer the pre-axial border tends to be supplied by the higher nerve.*

B. *Of two spots in the pre-axial area, the lower tends to be supplied by the lower nerve; and of two spots in the postaxial area, the lower tends to be supplied by the higher nerve.*[1]

The disposition of the cutaneous areas of the segmental nerves in the limb, as determined by Sherrington for the pelvic limb of the monkey, is shown diagrammatically in fig. 83. The several fields are seen to be arranged in regular order between lines continued obliquely outwards from the axial line of the limb over the dorsal and ventral surfaces. The fields of the pre-axial nerves constitute a descending series, the sixth lumbar field spreads from the end of the axial line to the extremity of the limb, and the fields of the postaxial nerves, less numerous than the pre-axial, form an ascending series.

Upper limb.—The pre-axial border extends from about the middle of the clavicle outwards and downwards between the deltoid and pectoralis major muscles, and then along the outer side of the arm and forearm to the thumb; the postaxial border from the axilla down the inner side of the arm and forearm to the ulnar side of the little finger. The dorsal surface comprises the scapular and deltoid regions and the back of the arm, forearm, and hand, the ventral surface, the pectoral region, the front of the arm and forearm, and the palm of the hand. The pre-axial area of the limb is supplied by the fifth and sixth cervical nerves, and the postaxial by the eighth cervical and first and second thoracic nerves. The seventh cervical nerve does not become superficial on the ventral aspect until the hand is reached, although on the dorsal aspect it appears earlier in the lower external cutaneous branch of the musculo-spiral, but here it is probably distributed to the lower part of the area of that nerve. The digits are supplied by the sixth, seventh, and eighth cervical, and first thoracic nerves, in this order, from the radial (pre-axial) to the ulnar (postaxial) side.

The *shoulder*, supplied superiorly by the descending branches of the cervical plexus (3, 4 *c*), receives its cutaneous nerves inferiorly from the circumflex nerve (5, 6 *c*).

The *arm* internally is supplied by the intercosto-brachial nerve (2 *t*) and the lesser internal cutaneous nerve (1 *t*). The inner and anterior part is supplied by the internal cutaneous nerve (8 *c*, 1 *t*), and the posterior and outer parts by the circumflex (5, 6 *c*), and by the internal and external branches of the radial nerve (6, 7, 8 *c*).

The *forearm*, anteriorly and on the outer side, is supplied by the musculo-cutaneous (5, 6 *c*); on its outer and posterior aspect by the lower external cutaneous branch of the musculo-spiral

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[1] 'The Minute Anatomy of the Brachial Plexus,' Proc. Roy. Soc. xli.

(6, 7, 8 *c*), and inferiorly by the radial branch (6, 7 *c*) of the same nerve. On the inner side, both in front and behind, is the internal cutaneous nerve (8 *c*, 1 *t*), and inferiorly are branches of the ulnar (8 *c*, 1 *t*).

On the *back of the hand* are the radial and ulnar nerves, the radial (6, 7 *c*) supplying about three fingers and a-half or less, and the ulnar (8 *c*) one and a-half or more.

On the *front of the hand*, the median nerve (6, 7, 8 *c*, 1 *t*) supplies three fingers and a-half, and the ulnar (1 *t* or 8 *c*, 1 *t*) one and a-half. In the *palm* is a branch of the median, and also a branch of the ulnar, given off above the wrist. On the *thenar eminence* are branches of the musculo-cutaneous, median, and radial nerves.

Lower limb.—The pre-axial and postaxial borders of the limb are not so readily traced as in the case of the upper limb, owing to the displacement which has taken place with the marked rotation of the lower limb during development, and the great extension of the area supplied by dorsal branches of the limb-nerves, with a corresponding reduction of the ventral area. The pre-axial border may be represented by a line following the course of the saphenous vein from the groin along the inner border of the sartorius to the knee, and thence along the inner border of the tibia to the ankle and inner border of the foot; and the postaxial border by a line running from the coccyx along the lower border of the gluteus maximus, thence down the postero-lateral aspect of the thigh to the back of the head of the fibula, and descending along the leg over the external malleolus to the outer border of the foot (Paterson). The dorsal surface corresponds to the buttock, the front of the thigh and leg, and the dorsum of the foot, while the ventral surface is on the inner side and the back of the thigh, the back of the leg, and the sole of the foot. The skin of the upper end of the limb, especially on its dorsal aspect, is supplied by nerves arising above and below those forming the limb-plexus. Thus the skin of the buttock receives its nerves from the lateral cutaneous offsets of the last thoracic and first lumbar nerves, and from the dorsal primary divisions of the lumbar and sacral nerves, while the ventral division of the first lumbar nerve reaches the upper part of the thigh in front. Along the pre-axial border are the second, third, and fourth lumbar nerves, while along the postaxial border are found the first, second, and third sacral. It will be observed that both of the lines are overstepped to some extent by nerves of dorsal origin, and that the area supplied by ventral nerves is reduced to a strip along the postero-internal part of the thigh, over but not completely covering the hamstring and adductor muscles, and along the back of the leg, but spreading out in the foot to the whole breadth of the sole. The fifth lumbar nerve does not become cutaneous on the ventral aspect until the sole is reached, but on the dorsal aspect it appears earlier in the lateral cutaneous branch of the peroneal. The toes are supplied by th

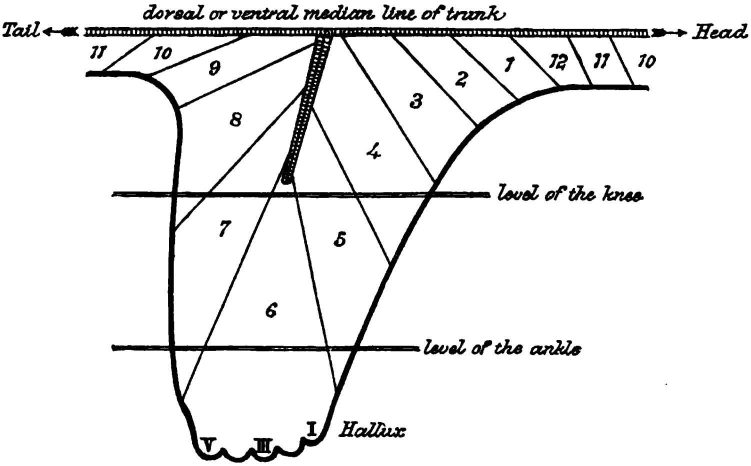


FIG. 83.—SCHEME OF THE SENSORY SPINAL SKIN-FIELDS OF THE HIND-LIMB OF MONKEY (*Macacus rhesus*). (Sherrington.)

10, 11, 12, areas of lower thoracic nerves; 1–7, areas of lumbar nerves; 8–11, areas of sacral and caudal nerves. Of the seven lumbar nerves in this monkey, the second and seventh correspond respectively to the first lumbar and first sacral nerves of man. The overlapping of the skin-fields is not indicated. The arrangement is the same on the dorsal and ventral aspects.

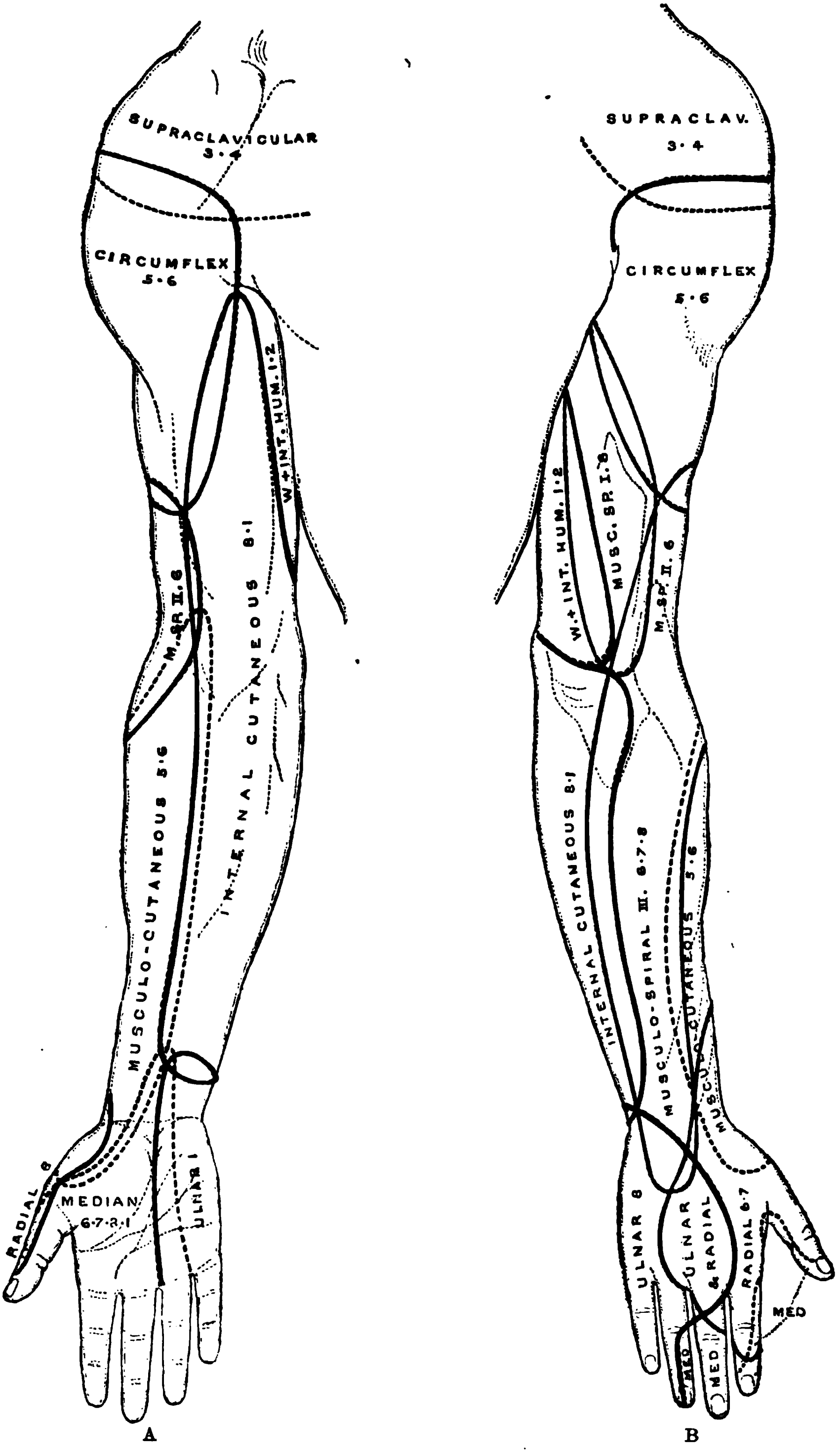

SUPRACLAVICULAR
3·4
CIRCUMFLEX
5·6
W.+INT. HUM. 1·2
M. SP. II. 6
INTERNAL CUTANEOUS 8·1
MUSCULO-CUTANEOUS 5·6
RADIAL 6
MEDIAN
6·7·8·1
ULNAR 1
A
SUPRACLAV.
3·4
CIRCUMFLEX
5·6
W.+INT. HUM. 1·2
MUSC. SP. I. 8
M. SP. II. 6
INTERNAL CUTANEOUS 8·1
MUSCULO-SPIRAL III. 6·7·8
MUSCULO-CUTANEOUS 5·6
ULNAR 8
ULNAR & RADIAL
RADIAL 6·7
MED
MED
MED
B

FIG. 84.—(For explanation, see opposite page.)

fourth and fifth lumbar, and the first and second sacral nerves, in this order, from the pre-axial to the postaxial side.

The *buttock* is supplied from above by the cutaneous branches of the dorsal divisions of the lumbar nerves, with the iliohypogastric (1 *l*) and lateral branch of the last thoracic nerves; internally by the dorsal divisions of the sacral nerves; externally by the posterior branch of the lateral cutaneous nerve (2, 3 *l*) proceeding from the front; and inferiorly by the perforating cutaneous nerve (2, 3 *s*) and branches of the posterior cutaneous nerve (1, 2, 3 *s*) proceeding from below.

The *thigh* is supplied externally by the lateral cutaneous nerve (2, 3 *l*) from the lumbar plexus; posteriorly, and in the upper half of its inner aspect, by the posterior cutaneous (1, 2, 3 *s*); anteriorly, and in the lower half of the inner aspect, by the anterior cutaneous branches (2, 3 *l*) of the femoral, the latter being frequently assisted by the obturator nerve (2, 3, 4 *l*).

The *leg* is supplied posteriorly by the terminal branches of the posterior cutaneous of the thigh (1, 2, 3 *s*) and the sural and lateral cutaneous nerves of the calf; internally by the saphenous (3, 4 *l*) and branches of the internal cutaneous of the thigh (2, 3 *l*) (or obturator); and outside and in front by cutaneous branches of the peroneal nerve (5 *l*, 1, 2 *s*) and by the musculo-cutaneous nerve (4, 5 *l*, 1 *s*).

On the *dorsum of the foot* are the branches of the musculo-cutaneous nerve (4, 5 *l*, 1 *s*), supplying all the toes with the exception of the adjacent sides of the first and second, which are supplied by the anterior tibial (4, 5 *l*, 1 *s*), and the outer side of the little toe, which, with the outer margin of the foot, is supplied by the sural cutaneous nerve (1, 2 *s*). The saphenous (3, 4 *l*) is the cutaneous nerve of the inner side of the foot.

The *sole of the foot* is supplied in its posterior part, together with the inner side of the heel, by the mesial calcaneal branches of the tibial nerve (1, 2 *s*). In front of this, the inner and larger part is supplied by the mesial plantar nerve (4, 5 *l*, 1 *s*), which extends to the inner three toes and a-half, while the outer part, with the remaining one toe and a-half, is supplied by the lateral plantar nerve (1, 2 *s*). Over the outer side of the heel, and along the outer margin of the sole, are branches of the sural cutaneous nerve (1, 2 *s*).

5. **To the viscera.**—There is strong reason for believing that the thoracic and abdominal viscera are supplied with sensory fibres derived from the spinal nerves, and passing through the sympathetic. In the dog Edgeworth has traced medullated fibres of medium size, which he regards as sensory, from the dorsal roots of the spinal nerves into the sympathetic, and thence to the several viscera; and his results are generally in close agreement with the inferences drawn from clinical observations in man (Head), although their accuracy in some particulars is disputed by Langley. Kölliker also recognises medullated sensory nerve-fibres passing without interruption from the dorsal roots of spinal nerves through the sympathetic to the viscera. Indirect evidence as to the source of these fibres is furnished by the seat of 'referred pain' in affections of the several organs. According to the hypothesis of Ross, the pain is referred in such cases to parts supplied by somatic sensory fibres having their origin from the nerves in which the sensory fibres of the affected viscus are contained, owing to diffusion of the irritation conveyed by the latter fibres in the corresponding segment of the grey matter of the spinal cord. The following table, taken from Head, shows the probable origin of the sensory fibres of the different organs:

Heart.—1, 2, 3 thoracic.

Lungs.—1, 2, 3, 4, 5 thoracic.

Stomach.—6, 7, 8, 9 thoracic. Cardiac end from 6, 7. Pyloric end from 9.

Intestines.—(*a*) Down to upper part of rectum, 9, 10, 11, 12 thoracic. (*b*) Rectum, 2, 3, 4 sacral.

FIG. 84.—CUTANEOUS AREAS OF THE NERVES OF THE UPPER LIMB. (G. D. Thane.)

A, anterior view; B, posterior view.

The areas supplied by the circumflex and musculo-spiral nerves, derived from the posterior cord of the brachial plexus, are circumscribed by red outlines; those of the ulnar, internal cutaneous, and lesser internal cutaneous nerves (W), from the inner cord of the plexus, together with the intercosto-brachial nerve, by blue lines; and those of the musculo-cutaneous from the outer cord of the plexus, with the median derived from both outer and inner cords, by interrupted black lines. The lower limit of the supra-clavicular nerves over the shoulder is also shown by a broken black line. The numerals following the names of the nerves indicate the spinal nerves from which the latter arise; 3, 4, 5, 6, 7, 8, the corresponding cervical nerves; 1, 2, the first and second thoracic nerves. The cutaneous branches of the musculo-spiral are distinguished as follows: I, internal cutaneous; II, upper, and III, lower external cutaneous

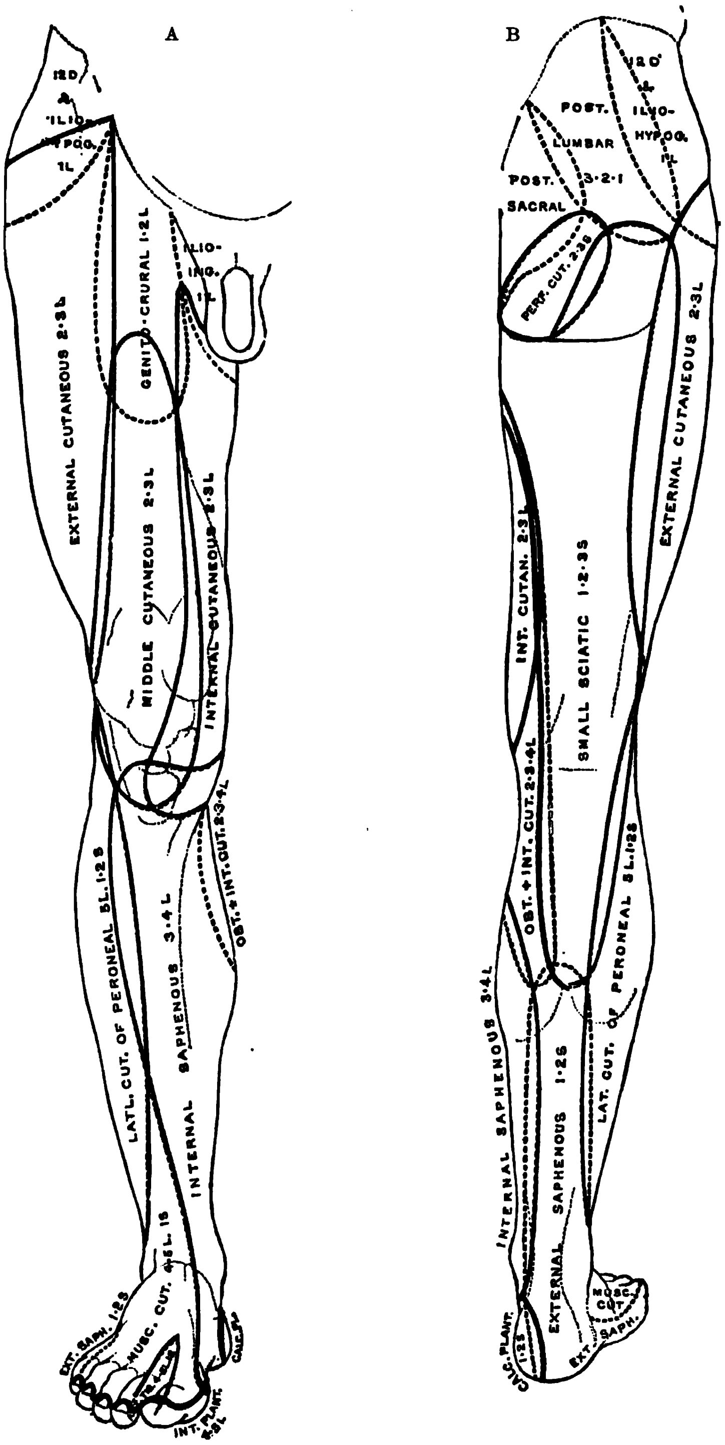

A
12D & ILIO-HYPOG. 1L
EXTERNAL CUTANEOUS 2·3L
GENITO-CRURAL 1·2L
ILIO-ING. 1L
MIDDLE CUTANEOUS 2·3L
INTERNAL CUTANEOUS 2·3L
OBT.+INT.CUT.2·3·4L
LATL.CUT. OF PERONEAL 5L.1·2S
INTERNAL SAPHENOUS 3·4L
MUSC. CUT. 4·5L. 1S
EXT. SAPH. 1·2S
MUSC. CUT.
INT. PLANT. 4·5L
CALC. PL.
B
12D & ILIO-HYPOG. 1L
POST. LUMBAR 3·2·1
POST. SACRAL
PERF. CUT. 2·3S
EXTERNAL CUTANEOUS 2·3L
INT. CUTAN. 2·3L
SMALL SCIATIC 1·2·3S
OBT.+INT. CUT. 2·3·4L
LAT. CUT. OF PERONEAL 5L.1·2S
INTERNAL SAPHENOUS 3·4L
EXTERNAL SAPHENOUS 1·2S
MUSC. CUT.
EXT. SAPH.
CALC. PLANT. 1·2S

FIG. 85.—(For explanation, see opposite page.)

Liver and gall-bladder.—(6 ?), 7, 8, 9, 10 thoracic.

Kidney and ureter.—10, 11, 12 dorsal. Upper part of ureter, 10 thoracic. At lower end of ureter, 1 lumbar tends to appear.

Bladder.—(*a*) Mucous membrane and neck of bladder, (1), 2, 3, 4 sacral. (*b*) Over-distension and ineffectual contraction, 11, 12 thoracic, and 1 lumbar.

Prostate.—10, 11 (12) thoracic.
1, 2, 3 sacral, and 5 lumbar.

Epididymis.—11, 12 thoracic, and 1 lumbar.

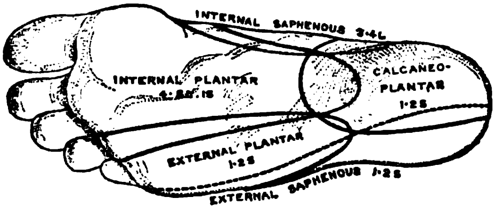


FIG. 86.—NERVE-SUPPLY OF THE SKIN OF THE SOLE. (G. D. Thane.)

Testis.—10 thoracic.

Ovary.—10 thoracic.

Appendages, &c.—11 and 12 thoracic, 1 lumbar.

Uterus.—(*a*) In contraction, 10, 11, 12 thoracic, and 1 lumbar. (*b*) Os uteri, (1), 2, 3, 4 sacral (5 lumbar very rarely).

DISTRIBUTION OF EFFERENT FIBRES OF CEREBROSPINAL NERVES, WITH A SUMMARY OF THE MUSCULAR SUPPLY.

(*a*) **Cerebral nerves.**—All the cerebral nerves supply muscles except the olfactory, the optic, and the acoustic. The formation of distinct mesodermic somites in the anterior part of the head of the human embryo has not been demonstrated; but three myotomes, which are probably derived from mesodermic somites, appear in the neighbourhood of the eye and are innervated by the third, fourth, and sixth nerves. The fifth, seventh, ninth, and tenth nerves supply muscles of the branchial arches, and may be termed branchiomeric. The muscles of the first or mandibular arch are supplied by the motor root (portio minor) of the fifth; these muscles are the temporal, masseter, two pterygoids, anterior belly of digastric, mylohyoid, tensor tympani, and tensor palati. The nerve of the second or hyoid arch is the seventh; it supplies the stapedius, the posterior belly of the digastric, and the stylohyoid, and a superficial sheet of muscle over the hyoid. From the lower part of this sheet the platysma is developed, while the upper part extends on to the face and scalp, and becomes differentiated into the muscles of the scalp, the pinna, the eyelids, except the levator palpebræ superioris, the nose, the cheek, and the lips. This migration of muscular tissue explains the formation of the pes anserinus of the facial and the marked divergence of its branches. The ninth nerve supplies the stylopharyngeus, a muscle of the third arch. The motor fibres of the vagus, with the medullary portion of the accessory, supply the muscles of the remaining arches, and also the muscular coat of the greater part of the fore-gut and its derivatives. The spinal part of the accessory and the hypoglossal nerves are really spinal nerves, and supply muscles derived from myotomes of the trunk.

FIG. 85.—CUTANEOUS AREAS OF THE NERVES OF THE LOWER LIMB. (G. D. Thane.)
A, anterior view; B, posterior view.

The areas enclosed by red lines are those supplied by the lateral cutaneous nerve, the middle and internal cutaneous, and the saphenous branches of the femoral (anterior crural) nerve, the perforating cutaneous nerve, and the lateral cutaneous, musculo-cutaneous, and anterior tibial branches of the peroneal nerve—*i.e.* the dorsal offsets of the limb-plexus. Those enclosed in blue lines are supplied by branches derived from the ventral offsets of the limb-plexus—viz. the calcaneo-plantar branch of the tibial and the plantar nerves. The area of the posterior cutaneous (small sciatic) is enclosed internally by a blue and externally by a red line, corresponding to the double nature of the nerve (see p. 104). The area of the inner side of the leg supplied by the obturator and internal cutaneous in common, and that supplied by the sural (external saphenous) are enclosed in interrupted black lines, the nerves concerned being derived partly from dorsal and partly from ventral divisions.

To muscles of the head and fore-part of the neck.—The *muscles of the orbit* are mostly supplied by the third cerebral nerve—the superior division of that nerve being distributed to the levator palpebræ and the superior rectus muscles, and the inferior division to the inferior and internal recti and the inferior oblique. The superior oblique muscle is supplied by the fourth nerve, and the external rectus by the sixth; while the tensor tarsi has no special nerve apart from those of the orbicularis palpebrarum, which are derived from the facial.

The *superficial muscles of the face and scalp*, which are associated in their action as a group of muscles of expression, together with the buccinator muscle, are supplied by the seventh cerebral nerve, the posterior auricular and occipitalis muscles being supplied by its posterior auricular branch.

The *deep muscles of the face* employed in mastication—viz. the temporal, masseter, and two pterygoid muscles—are supplied by the mandibular division of the fifth cerebral nerve.

Muscles above the hyoid bone.—The mylohyoid muscle and anterior belly of the digastric are supplied by a branch of the mandibular division of the fifth cerebral nerve; the posterior belly of the digastric muscle and the stylohyoid (together with the stapedius muscle) are supplied by branches of the facial. The muscles of the tongue receive their supply from the hypoglossal nerve; but the geniohyoid muscle is supplied (like the infrahyoid muscles) by the upper cervical nerves.

The larynx, pharynx, and soft palate.—The crico-thyroid muscle is supplied by the external laryngeal branch of the vagus nerve, and the other intrinsic muscles of the larynx by the recurrent laryngeal. The constrictors of the pharynx are supplied mainly by the bulbar part of the accessory nerve through the pharyngeal branch of the vagus and the pharyngeal plexus; and the levator palati, azygos uvulæ, palatopharyngeus, and palatoglossus are innervated from the same source. The stylopharyngeus, and possibly the middle constrictor in part, are supplied by the glossopharyngeal. The tensor palati is supplied through the otic ganglion, by the mandibular division of the fifth nerve (and the tensor tympani is supplied in the same way).

(*b*) **Spinal nerves.**—The skeletal muscles of the trunk are derived from the myotomes of the mesoblastic somites, and each myotome is supplied by a corresponding spinal nerve. This primitive segmental relation between the trunk muscles and nerves is liable to become obscured owing to the fact that the myotomes may undergo various changes, such as fusion, longitudinal or tangential splitting, migration or degeneration; but it is believed that each myotome retains the original connexion with its spinal nerve. In the process of development each myotome, which is at first dorsal in position, grows in a ventral direction and splits longitudinally into a dorsal portion supplied by the dorsal branch of a spinal nerve, and a ventral portion in which ventral fibres end. The dorsal divisions of the myotomes form all the muscles of the back, except those passing to the upper limb—viz. trapezius, latissimus dorsi, levator scapulæ, and rhomboids—and certain muscles belonging to the chest-wall (levatores costarum and the serrati postici) which are derived from the ventral divisions of the myotomes.

In the case of the short trunk-muscles, which are derived from a single myotome, the nervous supply is single, coming from the nerve of that segment. In more extended muscles, which are formed by the fusion of portions of several segments, the nervous supply is correspondingly multiple, although there is at times a reduction in the number of nerves in comparison with the segments from which the muscle appears to have been derived—*e.g.* in the quadratus lumborum and semispinalis capitis (complexus).

The exact origin of the mesoderm from which the limb-muscles are developed is not known, but as the nerve-supply of these muscles exhibits a distinctly segmental arrangement and is entirely from ventral primary divisions, it is probable that they are derived from the ventral portions of certain myotomes.

The nerve-supply of the limb-muscles presents the same general arrangement as that of the skin. The muscles are divisible into dorsal and ventral strata, which are supplied by dorsal and ventral branches distributed in a continuous segmental manner, so that of two muscles that nearer the head end of the body tends to be supplied by the higher nerve. The distribution of the motor nerves does not, however, entirely correspond to that of the cutaneous supply, as certain nerves, not represented in the limb-plexus, are drawn down during the development of the limb to supply the integument covering its proximal end. The motor fibres in each spinal segment supply a continuous band running parallel to the limb-axis from the trunk to the free end of the limb. The muscles of a given part of the limb and the overlying integument are therefore not necessarily supplied by the same segmental nerves (Sherrington).

1. **To muscles of the fore-part of the neck.**—*The muscles ascending to the hyoid bone and larynx*—viz. the sternohyoid, omohyoid, sternothyroid, and thyrohyoid—are supplied by the upper cervical nerves through their communications with the hypoglossal and the ansa cervicalis.

2. **To muscles belonging exclusively to the trunk, and muscles ascending to the skull.**—All those *muscles of the back* which act upon the spine and head—viz. the splenius, complexus, erector spinæ, and the muscles more deeply placed—receive their supply from the dorsal divisions of the spinal nerves.

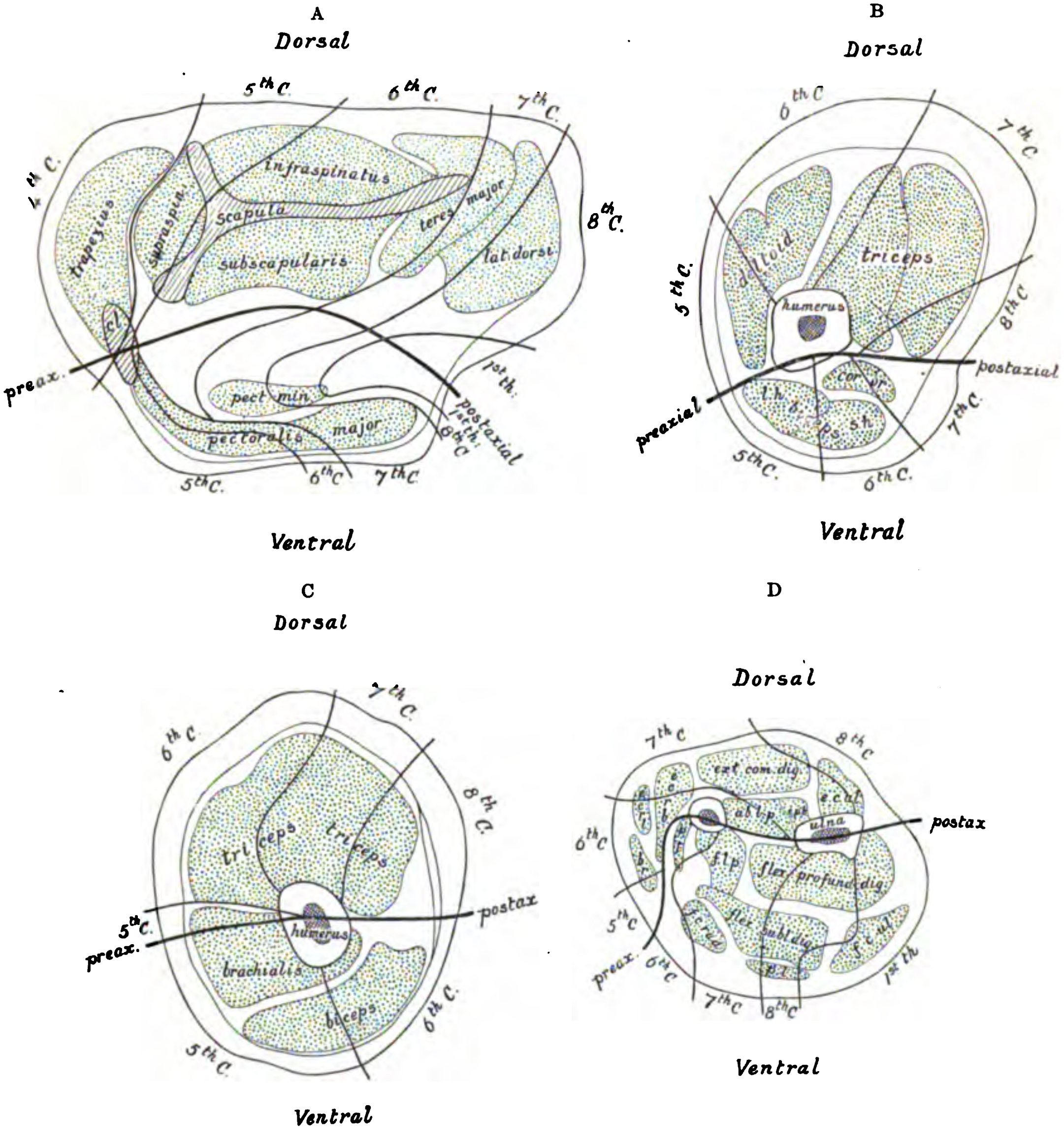

A
Dorsal
5th C.
6th C.
7th C.
8th C.
4th C.
infraspinatus
scapula
teres major
supraspin.
trapezius
subscapularis
lat. dorsi
cl.
preax.
1st th.
pect. min.
pectoralis major
1st th.
6th C
postaxial
5th C.
6th C
7th C
Ventral
B
Dorsal
6th C
7th C
5th C.
deltoid
triceps
humerus
8th C
postaxial
preaxial
cor. br.
bi. ceps. l.h. s.h.
7th C.
5th C.
6th C.
Ventral
C
Dorsal
7th C.
6th C
8th C.
triceps
triceps
5th C.
preax.
postax
humerus
brachialis
biceps
6th C.
5th C
Ventral
D
Dorsal
7th C
8th C
ext. com. dig.
e.c.r.l.
e.c.r.b.
e.c.ul.
abl.p.
ulna
postax
6th C
br.
f.l.p.
flex. profund. dig.
5th C
f.c.rad.
flex. subl. dig.
f.c.ul.
preax.
6th C
p.t.
1st th.
7th C
8th C
Ventral

Fig. 87.—Sections of the upper limb. A, through the axilla; B, through the upper part of the arm; C, through the lower part of the arm; D, through the forearm. (Modified from Bolk.)

The thick black line separates the dorsal and ventral portions of the limb and appears on the surface along the pre-axial and postaxial borders. The thinner black lines bound the dermatomes, myotomes, and sclerotomes of the spinal nerves. The nerve-supply of the muscles as represented in these diagrams does not always exactly agree with that given in the text.

The *sternomastoid* is supplied by the accessory nerve and a twig of the cervical plexus coming from the second cervical nerve.

The *rectus capitis anticus minor* and *rectus capitis lateralis* are supplied by the first cervical nerve, the *rectus capitis anticus major* by the upper four cervical nerves; the *longus colli* and *scaleni* receive twigs from nearly all the cervical nerves.

The *muscles of the chest-wall*—viz. the intercostals, subcostals, levatores costarum, serrati postici, and triangularis sterni—are supplied by the intercostal nerves.

The *obliqui*, *transversalis*, and *rectus* of the abdomen are supplied by the lower six to eight intercostal nerves; and the internal oblique and transverse muscles also get branches from the first lumbar nerve. The *cremaster* muscle is supplied by the genital branch of the genito-femoral nerve (1, 2 *l*).

The *quadratus lumborum* receives small branches from the last thoracic and upper one or two lumbar nerves.

The *diaphragm* receives the phrenic nerves from the fourth and fifth cervical nerves, branches from the lower intercostal nerves, and likewise sympathetic filaments from the plexuses round the phrenic arteries.

The *muscles of the urethra and penis* are supplied by the pudendal nerve (2, 3, 4 *s*), the *levator and sphincter ani* by the pudendal and the fourth sacral nerves; and the *coccygeus* muscle by the fourth and fifth sacral nerves.

3. **To muscles attaching the upper limb to the trunk.**—The *trapezius* and the *cleido-mastoid* receive the distribution of the accessory nerve, and, in union with it, offsets from the cervical plexus.

The *latissimus dorsi* receives the thoraco-dorsalis (7, 8 *c*).

The *rhomboidei* are supplied by a branch from the fifth cervical nerve.

The *levator scapulæ* is supplied by branches from the third and fourth cervical nerves, and partly also by the branch to the rhomboid muscles.

The *serratus anticus* (*magnus*) has a special nerve, the long thoracic, derived from the fifth, sixth, and usually the seventh cervical nerves.

The *subclavius* receives a branch from the place of union of the fifth and sixth cervical nerves.

The *pectorales* are supplied by the anterior thoracic branches of the brachial plexus, the larger muscle usually receiving fibres from the lower four cervical and first thoracic nerves, and the smaller from the last two cervical and first thoracic.

4. **To muscles of the upper limb.**—*Muscles of the shoulder.*—The supraspinatus and infraspinatus are supplied by the suprascapular nerve (5, 6 *c*); the subscapularis by the upper and lower subscapular nerves (5, 6 *c*); the teres major by the lower subscapular (5, 6 *c*); and the deltoid and teres minor by the circumflex nerve (5, 6 *c*).

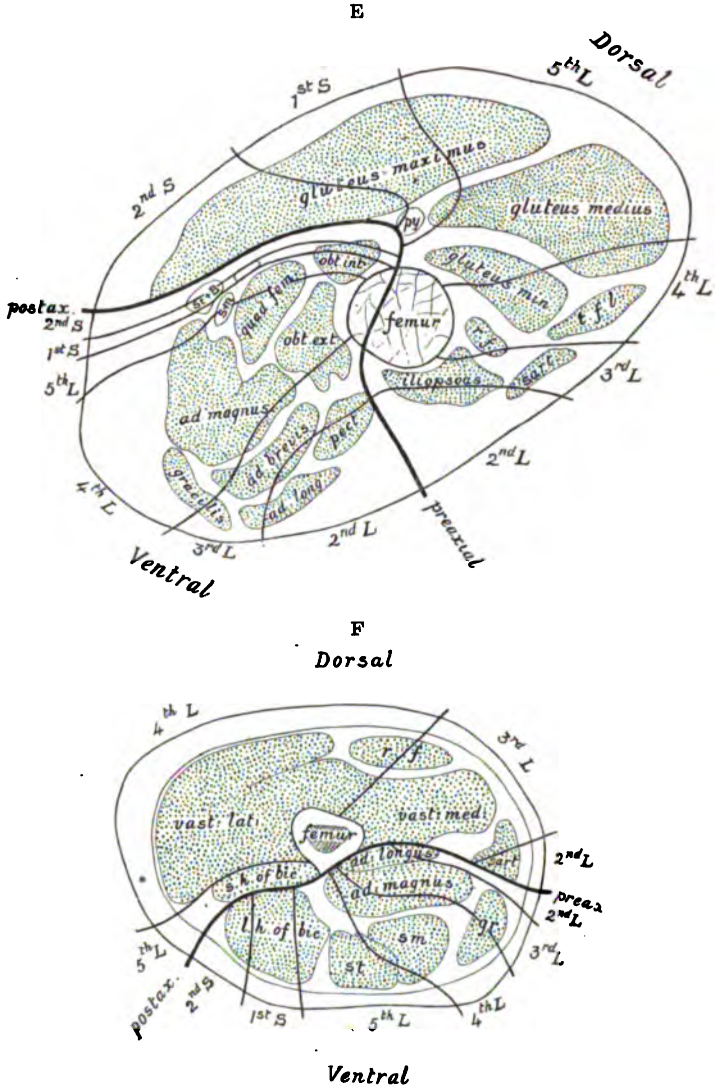
Posterior muscles of the arm and forearm.—The triceps (7, 8 *c*), anconeus (7, 8 *c*), brachio-radialis (6 *c*), and extensor carpi radialis longior (6, 7 *c*) are supplied by direct branches of the musculo-spiral nerve; while the extensor carpi radialis brevior (6, 7 *c*), the supinator (6 *c*), and the other extensor muscles in the forearm (7 *c*) receive their branches from the posterior interosseous division of that nerve.

Anterior muscles of the arm and forearm.—The coracobrachialis is supplied by the seventh cervical nerve, and the biceps and brachialis anticus by the fifth and sixth cervical nerves through the musculo-cutaneous trunk; the brachialis anticus likewise receives a twig frequently from the musculo-spiral nerve (6 *c*). The muscles of the front of the forearm are supplied by the median nerve, with the exception of the flexor carpi ulnaris and the inner half of the flexor profundus digitorum, which are supplied by the ulnar nerve. The offsets to the pronator teres and flexor carpi radialis are derived from the sixth cervical nerve, those to the flexor sublimis digitorum from the seventh and eighth cervical and first thoracic nerves, and those to the flexor carpi ulnaris, flexor longus pollicis, flexor profundus digitorum, and pronator quadratus from the eighth cervical and first thoracic nerves.

Muscles of the hand.—The abductor, opponens, and outer head of the flexor brevis pollicis are supplied by a branch of the median nerve (6, or 6 and 7 *c*). The lumbricales (7, 8 *c*, 1 *d*) receive their branches, the outer two from the median, and the inner two from the ulnar nerve. All the other muscles are innervated through the ulnar from the eighth cervical nerve.

5. **To muscles of the lower limb.**—*Muscles of the hip.*—The iliopsoas is supplied by the second and third lumbar nerves, the branches to the iliacus being given off from the femoral. The gluteus medius and minimus and the tensor fasciæ latæ are innervated by the superior gluteal (4, 5 *l*, 1 *s*), and the gluteus maximus by the inferior gluteal (5 *l*, 1, 2 *s*). The pyriformis (1, 2 *s*), quadratus femoris and inferior gemellus (4, 5 *l*, 1 *s*), and obturator internus with the superior gemellus (5 *l*, 1, 2 *s*), receive special branches from the sacral plexus. The obturator externus is supplied by the obturator nerve (3, 4 *l*).

Muscles of the thigh.—The sartorius (2, 3 *l*), pectineus (2, 3 *l*), and quadriceps extensor cruris (3, 4 *l*) are supplied by the femoral nerve. The adductor longus (2, 3 *l*), gracilis (2, 3, 4 *l*), adductor brevis (2, 3, 4 *l*), and adductor magnus (3, 4 *l*) are supplied by the obturator nerve, but the adductor magnus likewise receives a branch (4, 5 *l*) from the tibial portion of the sciatic nerve. The hamstring muscles are supplied by branches of the sciatic nerve, the semimembranosus (4, 5 *l*, 1 *s*), semitendinosus (5 *l*, 1, 2 *s*), and long head of the biceps (1, 2, 3 *s*), receiving their branches from its tibial division, and the short head of the biceps (5 *l*, 1, 2 *s*) from its peroneal division.


E
Dorsal
5th L
1st S
2nd S
gluteus maximus
py
gluteus medius
obt int
gluteus min
st.b
sm
quad fem
obt ext
femur
t.f.l
r.f
4th L
postax
2nd S
1st S
5th L
ad magnus
ad brevis
pect
iliopsoas
sart
3rd L
2nd L
gracilis
ad long
4th L
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preaxial
Ventral
F
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4th L
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vast. lat.
vast. med.
femur
ad longus
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2nd L
s.h. of bic
ad magnus
preax
2nd L
l.h. of bic
gr
sm
st
3rd L
5th L
postax
2nd S
1st S
5th L
4th L
Ventral

FIG. 88.—SECTIONS OF THE LOWER LIMB. E, THROUGH THE UPPER PART OF THE THIGH, DIVIDING THE FEMUR AT ITS NECK; F, THROUGH THE MIDDLE OF THE THIGH. (Modified from Bolk.) Diagrams constructed on the same plan as in fig. 87.

Anterior muscles of the leg and foot.—The muscles in front of the leg, together with the extensor brevis digitorum, are supplied by the anterior tibial nerve (4, 5 *l*, 1 *s*).

The *peroneus longus* and *brevis* are supplied by the musculo-cutaneous nerve (4, 5 *l*, 1 *s*).

Posterior muscles of the leg.—The gastrocnemius (1, 2 *s*), plantaris (4, 5 *l*, 1 *s*), popliteus (4, 5 *l*, 1 *s*), and soleus (5 *l*, 1, 2 *s*) are supplied by the tibial nerve. The flexor longus digitorum (5 *l*, 1 *s*), tibialis posticus (5 *l*, 1 *s*), and flexor longus hallucis (5 *l*, 1, 2 *s*) derive their nerves from the tibial.

Plantar muscles.—The flexor brevis digitorum, the abductor and flexor brevis hallucis, and the innermost lumbricalis are supplied by the mesial plantar nerve (5 *l*, 1 *s*); all the others, including the flexor accessorius and interosseous muscles, are supplied by the lateral plantar nerve (1, 2 *s*).

TABLE OF THE MUSCLES SUPPLIED BY THE SEVERAL SPINAL NERVES.

NERVE.	VENTRAL DIVISION.	DORSAL DIVISION.
1st cervical	Rectus lateralis, Rectus anticus minor and major, Geniohyoid, Infrahyoid muscles.	Rectus posticus major and minor, Obliquus superior and inferior, Complexus.
2nd cervical	Rectus anticus major, Longus colli, Sterno-cleido-mastoid, Geniohyoid, Infrahyoid muscles, Trapezius.	Obliquus inferior, Complexus, Splenius, Trachelomastoid.
3rd cervical	Rectus anticus major, Longus colli, Infrahyoid muscles, Scalenus medius, Levator scapulæ, (Sterno-cleido-mastoid),[1] Trapezius, (Diaphragm), Infrahyoid muscles.	Complexus, Transverso-spinales, Splenius, Erector spinæ.
4th cervical	Rectus anticus major, Longus colli, Scalenus medius (and anticus), Diaphragm, Levator scapulæ, Trapezius.	
5th cervical	Longus colli, Scaleni, (Diaphragm), Levator scapulæ, Rhomboidei, Serratus magnus, Subclavius, Supraspinatus, Infraspinatus, Teres minor, Subscapularis, (Teres major), Deltoid, Triceps, (Pectoralis major), Biceps, Brachialis, Extensores carpi radiales.	Transverso-spinales, Erector spinæ.
6th cervical	Longus colli, Scaleni, (Subclavius), Serratus anticus, (Supraspinatus, Infraspinatus, Teres minor), Subscapularis, Latissimus dorsi, Teres major, Deltoid, Pectoralis major, Triceps, Biceps, Brachialis, Pronator teres, Flexor carpi radialis, Supinator, Brachio-radialis, Extensores carpi radiales, Abductor, Opponens, and Flexor brevis pollicis.	
7th cervical	Longus colli, Scalenus medius, (Serratus anticus), Pectoralis major and minor, Latissimus dorsi, (Teres major), Coraco-brachialis, Triceps brachii, Anconeus, Flexor sublimis digitorum, (Flexor profundus digitorum, Flexor longus pollicis, Pronator quadratus), Extensores radiales, Extensors of digits, Extensor carpi ulnaris.	
8th cervical	Longus colli, Pectoralis major and minor, Latissimus dorsi, Triceps brachii, Anconeus, Flexors of digits, Flexor carpi ulnaris, Pronator quadratus, Adductores pollicis, Interossei, Abductor, Flexor brevis, and Opponens digiti quinti.	
1st thoracic	Pectoralis major and minor, Flexors of digits, Flexor carpi ulnaris, Pronator quadratus, Intercostales, Levator costæ, Serratus posticus superior, Abductor, Flexor brevis, and Opponens digiti quinti.	
2nd thoracic	Intercostales, Levator costæ, Serratus posticus superior, (Triangularis sterni).	
3rd thoracic 4th thoracic	Intercostales, Levatores costarum, Serratus posticus superior, Triangularis sterni.	

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[1] Names enclosed in parentheses indicate that the muscles are not always supplied from the nerve-root in question.

Nerve.	Ventral Division.	Dorsal Division.
5th thoracic 6th thoracic	Intercostales, Levatores costarum, Triangularis sterni, Obliquus externus, Rectus abdominis.	Transverso-spinales, Erector spinæ (*continued*).
7th thoracic 8th thoracic	Intercostales, Levatores costarum, Subcostales, Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis.	
9th thoracic 10th thoracic 11th thoracic	Intercostales, Levatores costarum, Subcostales, Serratus posticus inferior, Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis.	
12th thoracic .	(Quadratus lumborum), Obliquus externus, Obliquus internus, Transversalis abdominis, Rectus abdominis, Pyramidalis.	
1st lumbar . .	Quadratus lumborum, (Obliquus internus, Transversalis abdominis), Cremaster.	
2nd lumbar . .	(Quadratus lumborum), Cremaster, Psoas magnus, (Psoas parvus), Iliacus, Pectineus, Adductor longus, Adductor brevis, Gracilis, Sartorius.	
3rd lumbar . .	Psoas magnus, Iliacus, Pectineus, Adductor longus, Adductor brevis, Adductor magnus, Gracilis, Obturator externus, Sartorius, Quadriceps.	Multifidus spinæ, Erector spinæ.
4th lumbar . .	(Psoas magnus), Adductor brevis, Adductor magnus, Gracilis, Obturator externus, Quadriceps, Gluteus medius and minimus, Tensor fasciæ latæ, (Gluteus maximus, Obturator internus), Quadratus femoris, Semimembranosus, (Deep muscles of back of leg), Muscles of front and outer side of leg, Extensor brevis digitorum.	
5th lumbar . .	(Quadriceps), Adductor magnus, Gluteus maximus, medius, and minimus, Tensor fasciæ latæ, (Pyriformis), Quadratus femoris, Obturator internus, Hamstrings, Muscles of leg (except gastrocnemius), Extensor brevis digitorum, Inner muscles of sole.	
1st sacral . . .	Gluteus maximus, medius, and minimus, Tensor fasciæ latæ, Pyriformis, Obturator internus, Quadratus femoris, (Adductor magnus), Hamstrings, Muscles of leg and foot.	Multifidus spinæ.
2nd sacral . . .	Gluteus maximus, (Gluteus medius and minimus, Tensor fasciæ latæ, Pyriformis, Obturator internus, Semitendinosus, Biceps, (Muscles of front of leg, Peronei), Gastrocnemius, Soleus, Flexor longus hallucis, (Flexor longus digitorum, Tibialis posticus), Outer muscles of sole, Perineal muscles.	
3rd sacral . . .	(Pyriformis), Biceps, long head, (Gastrocnemius, Soleus, Muscles of sole), (Levator ani, Coccygeus), Perineal muscles.	
4th sacral . . .	Levator ani, Coccygeus, Perineal muscles.	
5th sacral . . .	(Coccygeus).	

The unstriped muscles of the viscera and other parts are also under the influence of fibres derived from the cerebrospinal nerves. These will be referred to in the description of the sympathetic.

This table of the muscles supplied by each spinal nerve is based mainly on dissections and embryological and pathological observations in man, but in part also upon physiological experiments in the monkey. In the case of some muscles the spinal nerve-supply is only approximate, as, owing to the difficulty in many cases of isolating the fibres between the spinal nerve-trunks and individual muscles, and also owing to our ignorance of the range of variation in both muscles and nerves, thoroughly reliable data are wanting.

From the above lists it will be seen that muscles of different action are often supplied from the same nerve-roots. Ferrier and Yeo concluded from their experiments in the monkey that the muscles called into action by the stimulation of a single nerve-root entering into the brachial or lumbo-sacral plexus form a group executing some definite co-ordinated movement of the limb, but Sherrington, in numerous observations on the same animal, failed to find evidence of such an association. Risien Russell, while supporting Ferrier and Yeo as to the co-ordination, also points out that (in the dog) when antagonistic muscles are represented in the same nerve-roots, one group predominates in one root and the opposite group in another root. Similarly, in man, at least for the larger joints of the limbs, the muscles producing the chief movements in opposite directions are mainly represented at different levels. Thus, the abductors of the shoulder are innervated mainly by the fifth cervical root, and the adductors by the sixth and seventh; the flexors of the elbow are supplied mainly through the fifth and sixth cervical nerves, and the extensors through the seventh and eighth; the extensors of the wrist predominate in the seventh, and the flexors in the eighth cervical and first thoracic nerves. So also in the lower limb, the flexors of the hip are represented mainly in the second and third lumbar nerves, and the extensors in the fifth lumbar and first and second sacral; the adductors in the third and fourth lumbar, and the abductors in the fifth lumbar and first sacral nerves; the flexors of the knee in the fifth lumbar and first and second sacral nerves, and the extensors in the third and fourth lumbar.

THE SYMPATHETIC SYSTEM.

This division of the nervous system consists of a somewhat complicated collection of ganglia, cords, and plexuses, the parts of which may, for convenience, be classed in two groups—viz. the principal gangliated cords, and the great prevertebral plexuses, with the nerves proceeding from them. The ganglia of union with cerebral nerves—viz. the ciliary, sphenopalatine, otic, and submaxillary ganglia, which agree in their connexions and structure with the ganglia of the sympathetic system, have already been described in connexion with the fifth nerve.

The nerves of the sympathetic system are distributed to the viscera and glandular organs generally, to the heart and blood-vessels, and to the unstriped muscles of the body. Some organs, however, receive nerves also from the cerebrospinal system directly—as the lungs, the heart, and the upper and lower parts of the alimentary canal.

The foundation of the sympathetic is constituted by medullated fibres, for the most part of very small size ($2{\cdot}6\,\mu$ and less), which pass by means of the *white rami communicantes* from certain of the cerebrospinal nerves into the cords and ganglia of the sympathetic. Here some of the fibres terminate in arborisations around the cells of the ganglia of the great sympathetic cord (*vertebral* or *lateral ganglia* of Gaskell), while others, which frequently run for a variable distance either upwards or downwards in the cord, pass by the *rami efferentes* to the prevertebral plexuses, where they may end similarly in the ganglia of those plexuses (*prevertebral* or *collateral ganglia*, Gaskell), or they may be continued on to the secondary plexuses, to break up in the ganglia close to or in the organs supplied (*terminal ganglia*, Gaskell). Some of the medullated fibres also pass through the several plexuses to the viscera or other parts without being interrupted in any of the ganglia above mentioned. From the cells of the ganglia other fibres, in great part if not entirely non-medullated, arise. These are the *sympathetic fibres* proper. They run partly in the *grey rami communicantes* to the spinal nerves, partly in the rami efferentes and the offsets of the collateral and terminal ganglia to their ultimate distribution.[1]

THE GANGLIATED CORDS.

The **great gangliated cords** (*trunci sympathici*) are two in number, and each consists of a series of ganglia (*ganglia trunci sympathici*), united by short intervening cords, sometimes double. These gangliated cords are placed symmetrically, partly in front, and partly on the side, of the vertebral column, extending from the base of the skull to the coccyx. Superiorly they are connected with plexuses which enter the cranial cavity, while inferiorly they converge on the sacrum, and terminate in a loop on the coccyx. The several portions of the cords are distinguished as cervical, thoracic, lumbar, and sacral, and in each of these parts the ganglia are equal in number, or nearly so, to the vertebræ against which they lie, except in the neck, where there are only three.

Connexion of the gangliated cords with the cerebrospinal system.—The ganglia are severally connected with the ventral primary divisions of the spinal nerves in their neighbourhood by short filaments called

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[1] The general and microscopic structure of the sympathetic system is dealt with in Part I. of Neurology.

rami communicantes, which are of two kinds, white and grey, the former consisting mainly of medullated fibres, and the latter of pale fibres. In some cases these are separate branches; in others they are united in one cord, which then consists of a white and a grey part. As a rule, the communicating branches join the ganglia of the sympathetic trunk, but sometimes they unite with the part of the cord connecting adjacent ganglia.

The *white rami communicantes* are composed, as stated above, mainly of very fine medullated fibres passing from the spinal nerves to the sympathetic cord. The fibres proceed from both roots of the spinal nerves, but to a greater extent from the ventral. It is probable that the fibres derived from the dorsal roots are for the most part afferent, but it has been shown by v. Lenhossék and others in the chick that the dorsal roots also contain fibres which spring from cells of the spinal cord, and are believed to enter the sympathetic (Kölliker). These fibres have, however, as yet not been observed in mammals, and Sherrington in the cat and monkey failed to find evidence of any fibres in the dorsal roots arising from cells of the spinal cord. Some of the medullated fibres are continued over the ganglia of the sympathetic cord to enter the efferent branches; others end in the ganglia, often ascending or descending for a considerable distance in the cord to reach ganglia at a higher or lower level than that of the communicating branch by which they pass to the sympathetic. The individual fibres also which terminate in the cord are not necessarily confined to one ganglion. According to Langley and Anderson, a single fibre may send branches to several (about four) ganglia. In this way the fibres contained in one communicating branch may have a wide distribution in the sympathetic.

White rami communicantes are not furnished by all the spinal nerves. According to Gaskell, by whose investigations the fundamental con-

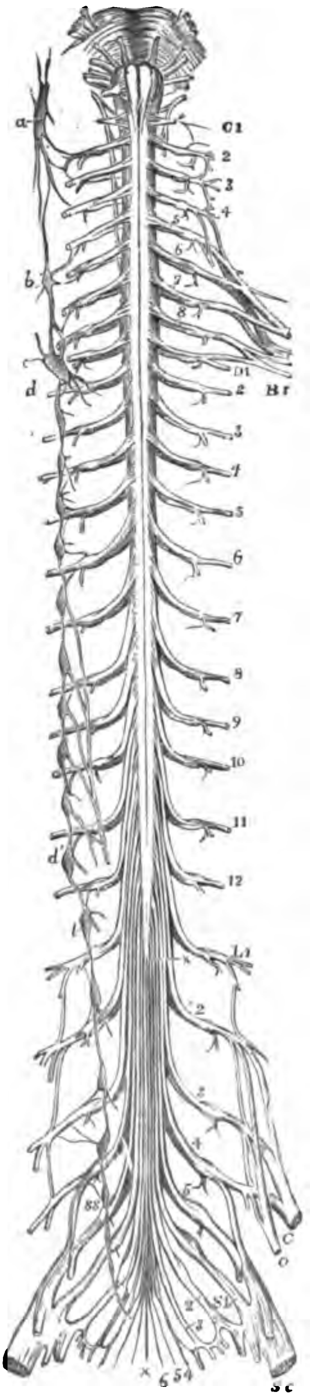

FIG. 89.—DIAGRAMMATIC OUTLINE OF THE SYMPATHETIC CORD OF ONE SIDE IN CONNEXION WITH THE SPINAL NERVES. (Allen Thomson.)

The full description of this figure will be found at p. 58.

On the right side the following letters indicate parts of the sympathetic nerves—viz. *a*, superior cervical ganglion, communicating with the upper cervical spinal nerves, and continued below into the great sympathetic cord; *b*, middle cervical ganglion; *c*, *d*, lower cervical ganglion united with the first thoracic; *d'*, eleventh thoracic ganglion: from the sixth to the ninth thoracic ganglia the origins of the great splanchnic nerve are shown, and from the tenth that of the small splanchnic nerve; *l*, first lumbar ganglion; *ss*, first sacral ganglion. In the whole extent of the sympathetic cord the twigs of union with the spinal nerves are shown.

stitution of the sympathetic and its relations to the cerebrospinal nerves were first made clear, they are found in the dog from the second thoracic to the second lumbar nerve inclusive; but Langley has shown that in the dog and cat white rami communicantes are given off by the spinal nerves from the first thoracic to the fourth lumbar, and in the rabbit from the first thoracic to the fifth lumbar inclusive. In man they exist from the first thoracic (ninth spinal) to the second lumbar (twenty-second spinal) nerves.[1] In a few cases they may extend to the eighth cervical. The visceral branches of the second, third, and fourth sacral nerves (*pelvic splanchnics* of Gaskell) correspond to white rami communicantes, although they do not join the sympathetic cord, but pass directly to the prevertebral plexuses; and in this group also are to be included the visceral branches of the accessory, vagus, glossopharyngeal, and facial nerves (*cervico-cranial rami viscerales*, Gaskell), as well as the short root of the ciliary ganglion from the third nerve.

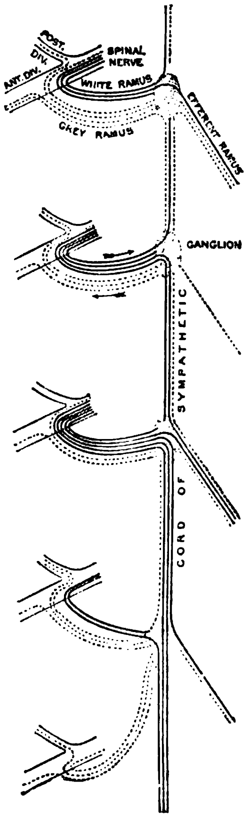

FIG. 90.—SCHEME OF THE SYMPATHETIC CORD AND ITS CONNEXIONS WITH THE SPINAL NERVES. (G. D. Thane.)

Medullated fibres passing into and through the sympathetic cord are represented by continuous lines, pale fibres arising from the sympathetic ganglia by dotted lines.

The medullated fibres distributed with the sympathetic system are classified by Kölliker as follows:

Sensory fibres which, when derived from spinal nerves, run in the dorsal roots.

Vaso- and *viscero-constrictors*, proceeding from certain cerebral (IX, X, XI) and spinal nerves, mainly from the ventral roots of the latter, but possibly also from the dorsal roots. These fibres all end in ganglia of the sympathetic, and their action is transmitted through pale fibres springing from the cells of the ganglia.[2]

Vaso-dilators and *viscero-inhibitory nerves*, given off from the above-mentioned cerebral nerves, and the ventral roots of spinal nerves. They are continued as medullated fibres, not forming any connexion with nerve-cells, to their respective organs.

The existence of special trophic and secretory fibres in the sympathetic is as yet uncertain.

The *grey rami communicantes* are found passing between the sympathetic cord and all the spinal nerves. Their pale fibres arise wholly from the nerve-cells of the ganglia of the sympathetic cord, and for the most part from the cells of the ganglion with which the branch is connected. Pale fibres arising from the cells of one ganglion, and running along the cord to leave by the grey ramus of the next ganglion, only occur exceptionally (Langley). On entering the ventral primary division of a spinal nerve, the fibres of the grey ramus are directed both peripherally and centrally. Of those passing centrally, some go off in the dorsal primary division of the nerve, others enter the sheath of the nerve, the surrounding tissue in the intervertebral foramen, and the dura mater, running up to the latter in the dorsal root. In the whole of the ventral root, and in the intradural portion of the dorsal root, there are no pale fibres (Gaskell). The fibres passing distally in the ventral and dorsal primary divisions of the spinal nerves have been shown, by experiments on animals, to supply vaso-motor nerves to the arteries of the body-wall and limbs, pilo-motor fibres to the muscles of the hairs, and secretory fibres to the sweat-glands.

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[1] N. B. Harman, 'The Caudal Limit of the Lumbar Visceral Efferent Nerves in Man,' Journ. Anat. and Phys. xxxii.; and 'Anterior Limit of the Cervico-thoracic Nerves in Man,' xxxiv.

[2] To this group must also be added the pilo-motor nerves, which have been shown by Langley and Sherrington to have a similar arrangement, as well as probably the motor nerves of the sphincter muscle of the iris, which pass from the third nerve through the ciliary ganglion. The last, however, present the peculiarity that the fibres of the short ciliary nerves arising from the cells of the ciliary ganglion are medullated.

It may also be observed here that doubt is thrown by Langley upon the universal validity of the rule that fibres passing from the cerebrospinal nerves to the sympathetic are medullated until they reach the ganglion in which they end, while the fibres arising from the ganglion-cells are always non-medullated. He thinks that spinal fibres sometimes lose their medulla some distance before reaching the cells among which they end, and on the other hand that fibres proceeding from sympathetic ganglion-cells may in some cases be medullated, like the short ciliary nerves. He also considers that a given fibre in the sympathetic is interrupted by a nerve-cell in one ganglion only.

Intermixed with the pale fibres in the grey rami communicantes there are also a few medullated fibres of varying size, even in regions where distinct white rami do not exist (Langley).

From each grey ramus a filament is given off to join the recurrent branch of the corresponding spinal nerve, which is distributed in the interior of the spinal canal (p. 56). Other filaments pass over the bodies of the vertebræ, supplying the intercostal and lumbar arteries, the ligaments, and the bones.

The portions of the sympathetic cord intervening between the ganglia are composed of a white and a grey part, the former, which is usually the larger, consisting of medullated fibres continued from the white rami communicantes, and the latter of pale fibres, which arise in the ganglia and run along the cord before entering the efferent branches.

The **rami efferentes** are the branches proceeding from the gangliated cord to the prevertebral plexuses, and likewise composed of medullated fibres of spinal origin and pale fibres springing from the ganglia.

CERVICAL PART OF THE GANGLIATED CORD.

In the neck, the gangliated cord is deeply placed behind the great cervical blood-vessels, being imbedded in the fascia forming the back of the carotid sheath, and resting on the muscles which immediately cover the fore-part of the vertebral column. It comprises three ganglia, the first of which is placed near the base of the skull, the second in the lower part of the neck, and the third close to the head of the first rib.

UPPER CERVICAL GANGLION.—This is the largest ganglion of the great sympathetic cord, 20 mm. or more long and 4–6 mm. wide. It is continued superiorly into an ascending branch, and tapers below into the connecting cord, so as to present usually a fusiform shape; but there is considerable variety in this respect in different cases, the ganglion being occasionally shorter and broader than usual, and sometimes constricted at intervals. It has the reddish-grey colour characteristic of the ganglia of the sympathetic system. It is placed on the rectus anticus major muscle opposite the second and third cervical vertebræ, lying behind the internal carotid artery, and to the inner side of the vagus nerve.

Connexion with spinal nerves.—At its outer side, the superior cervical ganglion is connected with the first four spinal nerves by means of slender cords, which belong to the group of grey rami communicantes. The branches to the third and fourth nerves often pierce the rectus anticus major muscle; and they may be given off from the upper part of the cord instead of directly from the ganglion.

The circumstance of this ganglion being connected with so many as four spinal nerves, together with its occasionally constricted appearance, is favourable to the view that it may be regarded as consisting of several ganglia which have coalesced.

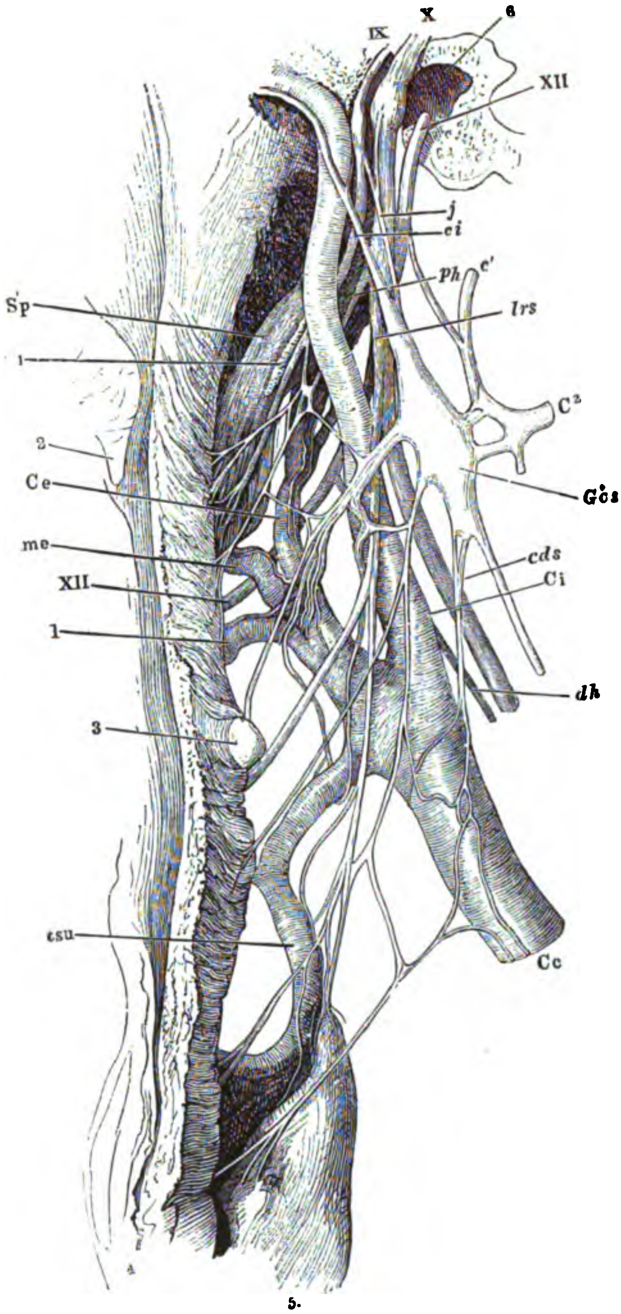

FIG. 91.—THE SUPERIOR CERVICAL GANGLION OF THE SYMPATHETIC, WITH ITS BRANCHES AND CONNEXIONS. (Henle.)

1, styloid process; 2, uvula; 3, great cornu of hyoid bone, pushing up the posterior wall of the pharynx; 4, œsophagus; 5, thyroid body; Sp, stylopharyngeus muscle.

Cc, common carotid artery; Ci, internal carotid; Ce, external carotid; tsu, superior thyroid; l, lingual; m e, facial.

IX, glossopharyngeal nerve; X, vagus; XII, hypoglossal; c^1, first cervical; c^2, second cervical; *ph*, pharyngeal branch of vagus; *lrs*, superior laryngeal; *dh*, descending cervical nerve; *Gcs*, superior cervical ganglion of sympathetic; *Ci*, ascending branch; *j*, jugular branch; *cds*, superior cardiac nerve.

The superior cervical ganglion is considered by Gaskell to be a distal or collateral ganglion. It receives its cerebrospinal fibres, which constitute the *cervical splanchnics* of Gaskell, from the upper thoracic nerves, these fibres ascending through the cervical part of the sympathetic cord.

Connexion with cerebral nerves.—Small twigs connect the ganglion or its cranial cord with the lower ganglion of the vagus, and with the twelfth cerebral nerve, near the base of the skull; and another branch (*nervus jugularis*), which is directed upwards from the ganglion, divides at the base of the skull into two filaments, one of which ends in the petrosal ganglion of the glossopharyngeal nerve; while the other, entering the jugular foramen, joins the ganglion of the root of the vagus.

From the lower part of the ganglion a filament sometimes runs forwards and downwards to join the external laryngeal nerve. This branch is described as normal by many anatomists, but according to Drobnik it is only exceptionally present.

Besides the branches connecting it with cerebral and spinal nerves, the first cervical ganglion gives off also the ascending branch, pharyngeal branches, the upper cardiac nerve, and branches to blood-vessels, as well as two or three filaments which pierce the prevertebral muscles to supply the upper cervical vertebræ and their ligaments.

Ascending branch and cranial plexuses.—The **ascending** or **carotid branch** of the first cervical ganglion (*n. caroticus internus*) is soft in texture and of a reddish-grey tint, seeming to be in some degree a prolongation of the ganglion itself. In its course to the skull, it is concealed by the internal carotid artery, with which it enters the carotid canal in the temporal bone, and it is then divided into two parts, which are placed one on the outer, the other on the inner side of the vessel.

The *external division* distributes filaments to the internal carotid artery, receives one or two carotico-tympanic twigs from the tympanic branch of the glossopharyngeal (p. 39), and, after communicating by means of other filaments with the internal division of the cord, forms the *carotid plexus.*

The *internal division*, rather the smaller of the two, supplies filaments to the carotid artery, and goes to form the *cavernous plexus.* The terminal parts of these divisions of the cranial cord are prolonged on the trunk of the internal carotid, and extend to the cerebral and ophthalmic arteries, around which they form secondary plexuses, those on the cerebral arteries ascending to the pia mater. One minute plexus enters the eyeball with the central artery of the retina.

Carotid plexus.—The carotid plexus (*plexus caroticus internus*), situated on the outer side of the internal carotid artery at its second bend (reckoning from below), or between the second and third bends, joins the fifth and sixth cerebral nerves, and gives many filaments to the vessel on which it lies.

Branches.—The connexion with the *sixth nerve* is established by means of one or two filaments of considerable size, which are supplied to that nerve where it lies by the side of the internal carotid artery.

The filaments connected with the *semilunar ganglion* of the fifth nerve proceed generally from the carotid plexus, but sometimes from the cavernous.

The *deep petrosal nerve* passes forwards from the outer side of the artery to the posterior aperture of the pterygoid canal, where it joins the large superficial petrosal from the facial to form the Vidian nerve, which is continued to the sphenopalatine ganglion (p. 22).

The *small deep petrosal nerve* passes between the carotid plexus and the tympanic plexus (p. 39).

Cavernous plexus.—The cavernous plexus, named from its position in the sinus of the same name, is placed below and rather to the inner side of the highest turn of the internal carotid artery. Besides giving branches on the artery, it communicates with the third, the fourth, and the ophthalmic division of the fifth cerebral nerves.

Branches.—The filament which joins the *third nerve* comes into connexion with it close to the point of division of that nerve.

The branch to the *fourth nerve,* which may be derived from either the cavernous or the carotid plexus, joins the nerve where it lies in the wall of the cavernous sinus.

The filaments connected with the *ophthalmic trunk of the fifth nerve* are supplied to its inner surface.

The *sympathetic root of the ciliary ganglion* passes from the cavernous plexus into the orbit, either separately, or in connexion with the naso-ciliary nerve, or, according to Reichart, with the third nerve (p. 18).

Minute filaments are furnished to the pituitary body.

Pharyngeal nerves and plexus.—These nerves arise from the forepart of the ganglion, and are directed obliquely inwards to the side of the pharynx. Opposite the middle constrictor muscle they unite with branches of the vagus and glossopharyngeal nerves; and by their union with these nerves the **pharyngeal plexus** is formed. Branches emanating from the plexus are distributed to the muscles and mucous membrane of the pharynx (p. 42). One or two filaments pass from these branches to the superior and external laryngeal nerves (fig. 91).

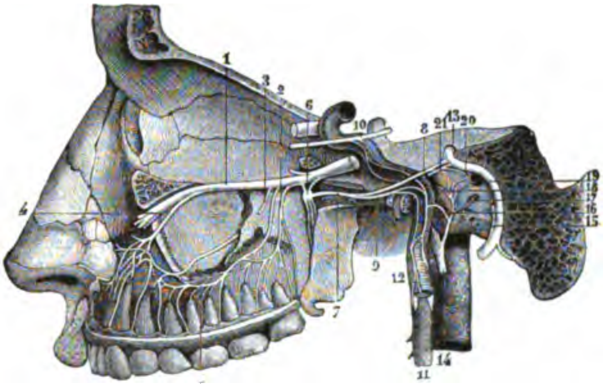

FIG. 92.—CONNEXIONS OF THE SYMPATHETIC NERVE THROUGH ITS CAROTID BRANCH WITH SOME OF THE CEREBRAL NERVES. (From Sappey, after Hirschfeld and Leveillé.)

The full description of this figure will be found at p. 21. The following numbers refer to sympathetic nerves and their connexions: 6, sphenopalatine ganglion; 7, nervus canalis pterygoidei (Vidian); 9, deep petrosal nerve; 10, a part of the sixth nerve receiving twigs from the carotid plexus of the sympathetic; 11, superior cervical sympathetic ganglion; 12, its prolongation in the carotid branch; 15, tympanic nerve; 16, twig uniting it to the sympathetic.

Superior cardiac nerve.—Each of the cervical ganglia of the sympathetic usually furnishes a cardiac branch, the three being named respectively the upper, middle, and lower cardiac nerves.

These branches are continued singly, or in connexion, to the large prevertebral centre (cardiac plexus) of the thorax. Their size varies considerably, and where one branch is smaller than usual, another will be found to be increased in size, as if to compensate for the defect. There are some differences in the disposition of the nerves of the right and left sides.

The *superior cardiac nerve of the right side* proceeds generally from two or more branches of the ganglion, with, in some instances, an offset from the cord connecting the first two ganglia. In its course down the neck the nerve lies in the back of the carotid sheath, along the front of the longus colli muscle; it crosses either in front of or, less frequently, behind the inferior thyroid artery, and is placed in front of the recurrent laryngeal nerve. Entering the thorax, it passes in some cases before, in others behind, the subclavian artery, and is directed along the innominate artery to the back part of the arch of the aorta, where it ends in the deep cardiac plexus, a few small filaments continuing also to the front of the great vessel. Some branches accompany the inferior thyroid artery to be distributed to the thyroid body.

In its course downwards this cardiac nerve is repeatedly connected with other branches of the sympathetic, and with the vagus nerve. Thus, about the middle of the neck it is joined by one or more filaments from the external laryngeal nerve; and, rather lower down, by one or two filaments from the trunk of the vagus nerve (upper cervical cardiac branches); lastly, on entering the chest it joins with the recurrent laryngeal.

The *superior cardiac nerve of the left side* has, while in the neck, the same course and relations as that of the right side. Within the chest it follows the left carotid artery to the arch of the aorta, and usually crosses over that vessel to enter the superficial cardiac plexus. In some cases, however, this nerve ends, either wholly or in part, in the deep cardiac plexus, and it then descends behind the arch of the aorta.

Varieties.—The cardiac nerves vary greatly in their disposition, and in many cases it is difficult, if not impossible, to recognise the arrangement which is described as typical. The superior cardiac nerve of the right side, instead of passing to the thorax in the manner stated above, may join the cardiac branch furnished from one of the other cervical ganglia. This nerve is sometimes wanting, especially on the right side; in such cases it appears to be replaced by a larger superior cardiac offset from the vagus or its external laryngeal branch (M. Alpiger).

Drobnik describes a special *pretracheal branch* which is given off from the communication between the superior cardiac nerve and the recurrent laryngeal; it descends on the trachea, and terminates partly in the pericardium, partly in the anterior pulmonary plexus.

Branches to blood-vessels.—The nerves which ramify on the arteries (*nervi carotici externi*) spring from the front of the ganglion, and twine round the trunk of the external carotid artery (*plexus caroticus externus*). They are also prolonged on the branches of the artery, forming upon them slender plexuses which are named like the arteries they accompany. From the plexus on the facial artery is derived the filament which forms the sympathetic root of the submaxillary ganglion; and from that on the middle meningeal artery twigs are described as extending to the otic ganglion, as well as to the geniculate ganglion of the facial nerve (*external superficial petrosal nerve*, p. 33). One filament descends from these nerves to the carotid gland.

Microscopic ganglia are frequently met with in the vascular plexuses, and several larger ones of more constant occurrence have been described. The most important of these is the *temporal ganglion*, about 2 mm. in length, situated on the external carotid artery at the place of origin of the posterior auricular branch; it is said to receive a filament from the stylohyoid branch of the facial nerve.

MIDDLE CERVICAL GANGLION.—The middle ganglion, much the smallest of the cervical ganglia, is placed on the sympathetic cord at or near the spot where it crosses the inferior thyroid artery, about opposite the sixth or seventh cervical vertebra. It is usually connected by grey branches with the fifth and sixth spinal nerves, but in a somewhat variable manner. It gives off thyroid branches and the middle cardiac nerve.

Thyroid branches.—From the inner side of the ganglion some twigs proceed along the inferior thyroid artery to the thyroid body, where they join the recurrent laryngeal and the external laryngeal nerves. While on the artery, these branches communicate with the upper cardiac nerve.

Cardiac branch.—The *middle cardiac nerve* (deep or great cardiac nerve) *of the right side* is prolonged to the chest either in front of or behind the subclavian artery. In the chest it lies on the trachea, where it is joined by filaments of the recurrent laryngeal nerve, and it ends in the right side of the deep cardiac plexus. While in the neck, this nerve communicates with the upper cardiac nerve and the recurrent branch of the vagus.

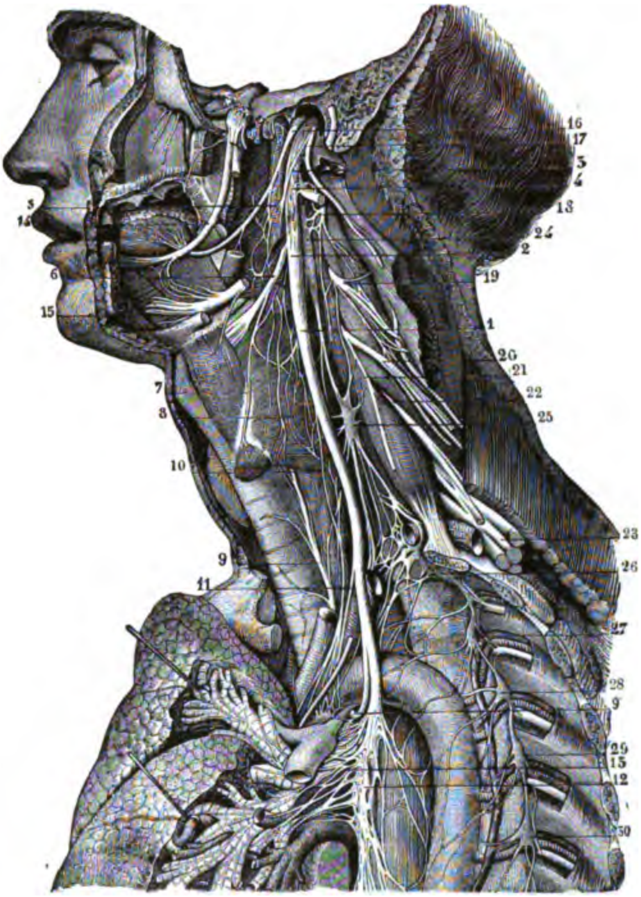

FIG. 93.—CONNEXIONS OF THE CERVICAL AND UPPER THORACIC SYMPATHETIC GANGLIA AND NERVES ON THE LEFT SIDE. (From Sappey, after Hirschfeld and Leveillé.)

The full description of this figure will be found at p. 40. The following numbers refer to the sympathetic ganglia and nerves, and those immediately connected with them: 5, pharyngeal plexus; 12, 13, posterior pulmonary plexus; and to the reader's left, above the pulmonary artery, the superficial cardiac plexus; 24, superior cervical ganglion of the sympathetic; 25, middle cervical ganglion; 26, conjoined inferior cervical and first thoracic ganglia; 27, 28, 29, 30, second third, fourth, and fifth thoracic ganglia.

On the *left side*, the middle cardiac nerve enters the chest between the left carotid and subclavian arteries, and joins the left side of the deep cardiac plexus.

Varieties.—The middle cervical ganglion is often absent, and in that case the middle cardiac nerve is given off by the interganglionic cord. On the other hand, it is sometimes double (fig. 94). The smaller upper portion (A) is the middle cervical ganglion of Arnold and Luschka, the thyroid ganglion of Krause; while the larger lower portion (B) is the middle cervical ganglion of Swan and Krause, the inferior cervical ganglion of Arnold, Luschka, and Rüdinger. The single ganglion is more frequently in the latter situation.

This part of the cord is sometimes placed behind the inferior thyroid artery, or it may be divided so that the artery is enclosed in a loop of the nerve.

LOWER CERVICAL GANGLION.—The lower cervical ganglion is irregular in shape, usually somewhat flattened and round, or semilunar, and is frequently united to the first thoracic ganglion, the common mass being described as the first thoracic ganglion by many authors. It lies over the first costo-central articulation, in the lateral angle between the subclavian and vertebral arteries. The connecting cord between the middle and lower cervical ganglia usually passes behind the vertebral artery, but in some cases, especially on the left side, the interganglionic cord forms a ring around the vessel. The two ganglia are also united by the ansa subclavia (see below).

The inferior cervical ganglion is connected to the lowest two cervical nerves by grey communicating branches, and it gives off the lower cardiac nerve and offsets to blood-vessels.

Cardiac branch.—The *lower cardiac nerve*, issuing from the inferior cervical ganglion, or from the first thoracic, inclines inwards on the *right side*, behind the subclavian artery, and terminates in the cardiac plexus behind the arch of the aorta. It communicates with the middle cardiac and recurrent laryngeal nerves behind the subclavian artery.

On the *left side*, the lower cardiac often becomes blended with the middle cardiac nerve, and the cord resulting from their union terminates in the deep cardiac plexus.

Branches to blood-vessels.—From the lowest cervical and first thoracic ganglia slender grey branches ascend along the vertebral artery in its canal, forming a plexus (*plexus vertebralis*) round the vessel by their intercommunications, and supplying it with offsets. This plexus is connected with the cervical spinal nerves as they cross the vertebral artery, and its ultimate ramifications are continued on the intracranial branches of the vertebral and basilar arteries.

Ansa subclavia (*Vieussenii*).—This name is given to a small cord, often double, which passes between the middle cervical and the lower cervical, or first thoracic, ganglia, in front of the subclavian artery, forming a loop around that vessel, and supplying it with small offsets (*plexus subclavius*). From the latter, filaments pass to the internal mammary artery, and in some cases form a communication with the phrenic nerve.

A direct twig of communication to the phrenic nerve is often given off from the inferior cervical ganglion, less frequently from the middle cervical ganglion.

The **stellate ganglion** of the dog and cat corresponds to the united lower cervical and upper three or four thoracic ganglia of man. In the rabbit the name *ganglion stellatum* was used for the lower cervical ganglion, corresponding to the middle cervical ganglion of man, by Ludwig and Thiry, whereas Cyon applied it to the first thoracic ganglion, which corresponds to the lower cervical ganglion in man (Krause).

FUNCTIONAL DISTRIBUTION OF THE CERVICAL SYMPATHETIC.

The sets of fibres which have been recognised in the cervical sympathetic, and their probable origin, are as follows:

Pupillo-dilator fibres, arising from the first, second, and third thoracic nerves. They pass upwards in the ascending branch of the superior cervical ganglion, and thence to the semilunar ganglion, reaching the eyeball through the first division of the fifth and the long ciliary nerves. (It is stated by many observers that pupillo-dilator fibres are contained also in the seventh and eighth cervical nerves.)

Motor fibres to the involuntary muscle of the orbit and non-striped part of the levator palpebræ, from the highest four or five thoracic nerves (Langley).

Vaso-motor fibres of the head. *Vaso-constrictor fibres* are given off in the dog and cat chiefly by the second, third, and fourth thoracic nerves, in the rabbit by the thoracic nerves from the second to the eighth (Langley). There is also evidence as to the existence of *vaso-dilator fibres* (Dastre and Morat), but the origin of these has not been fully ascertained.

Secretory fibres of the salivary glands, mainly from the second and third thoracic nerves.

Pilo-motor fibres of the face and neck, arising in the monkey from the second, third, fourth, and fifth thoracic nerves (Sherrington).

In all the foregoing groups the fibres of spinal origin terminate, and fibres of sympathetic origin arise, in the superior cervical ganglion.

Accelerator fibres of heart, derived from the upper four or five thoracic nerves, but chiefly from the second and third. The spinal fibres end and sympathetic fibres begin in the middle and lower cervical (perhaps also the first thoracic) ganglia.

Sweat-glands of head and neck and upper limb (Purves Stewart).

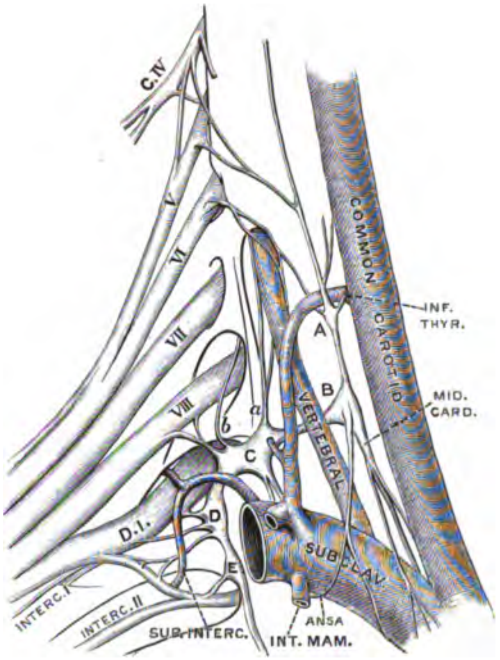

FIG. 94.—THE SYMPATHETIC AT THE LOWER PART OF THE NECK. (G. D. Thane.)

A, B, middle cervical ganglion in two pieces; C, inferior cervical ganglion; D and E, first and second thoracic ganglia.

a, vertebral offset of inferior cervical ganglion; *b*, branch which ascends through the foramen in the transverse process of the last cervical vertebra to join the seventh nerve.

Below C are the origin of the inferior cardiac nerve, and the termination of the ansa subclavia. The arteries have been drawn downwards and inwards in order to display the nerves. The middle cervical ganglion is, therefore, in a lower position than natural; and the communication between the middle and lower ganglia is directed more transversely than would be the case if the parts were in their natural place.

THORACIC PART OF THE GANGLIATED CORD.

In the thorax the gangliated cord is placed at the side of the spinal column, along a line passing over the costo-central articulations. It is covered by the pleura, and crosses the intercostal blood-vessels.

The ganglia are commonly eleven in number, seldom twelve. The first, when distinct, is larger than the rest, and lies at the vertebral extremity of the first intercostal space; but it is often blended with the lower cervical ganglion. The succeeding ganglia are small, oval or triangular in form, and correspond generally to the heads of the ribs from the third to the eleventh; while the last is placed a little in front of the head of the twelfth rib, about the upper border of the last thoracic vertebra.

Connexion with spinal nerves.—The branches of connexion between the thoracic spinal nerves and the ganglia of the sympathetic are usually two in number for each ganglion, one of these being white and the other grey (p. 149).

Branches of the ganglia.—The branches furnished by the *upper four or five ganglia* are small, and are distributed in great measure to the vertebræ and ligaments, and to the descending thoracic aorta (fig. 93), on which they form, together with filaments proceeding lower down from the great splanchnic nerve, a slender network (*plexus aorticus thoracalis*). From the second, third, and fourth ganglia offsets pass also to the posterior pulmonary plexus (p. 159).

The branches furnished by the *lower six or seven ganglia* unite into three cords on each side, which pass down to join plexuses in the abdomen, and are distinguished as the great, the small, and the smallest splanchnic nerves (*abdominal splanchnics* of Gaskell).

The **great splanchnic nerve** is formed by the union of roots which are given off by the thoracic ganglia from the fifth or sixth to the ninth or tenth inclusive. The trunk thus constituted descends obliquely forwards over the bodies of the thoracic vertebræ, and after perforating the crus of the diaphragm terminates in the upper part of the cœliac ganglion: some of the fibres may occasionally be followed to the suprarenal body and the renal plexus. This nerve is remarkable from its white colour and firmness, due to its consisting in large part (four-fifths according to Rüdinger) of medullated fibres, which are continued directly from the spinal nerves; from the highest root they may be traced upwards along the sympathetic cord as far as the third thoracic ganglion and nerve, or even higher.

In the chest the great splanchnic nerve is not infrequently divided into parts, and forms a plexus with the small splanchnic nerve. In many cases also a small ganglion (*splanchnic ganglion*) is formed on it, usually confined to the inner part of the nerve, over the last thoracic vertebra, or the last but one; and when it presents a plexiform arrangement, several small ganglia have been observed on its divisions. According to Cunningham, the splanchnic ganglion is always present on the right side.

From the great splanchnic nerve and the splanchnic ganglion filaments are given to the front of the vertebræ and the aorta.

In eight instances out of a large number of bodies, Wrisberg observed a fourth splanchnic nerve (*nervus splanchnicus supremus*). It is described as formed by offsets from the cardiac nerves, and from the lower cervical as well as some of the upper thoracic ganglia.

The **small splanchnic nerve** springs from the ninth and tenth (sometimes the tenth and eleventh) thoracic ganglia, or from the neighbouring part of the cord. It passes along with the preceding nerve, or separately, through the diaphragm, and ends in the lower part of the cœliac (or aortico-renal) ganglion. In the chest, this nerve often communicates with the great splanchnic nerve; and in some instances it furnishes a branch to the renal plexus, especially if the lowest splanchnic nerve is very small or wanting.

The **smallest splanchnic nerve** (*nervus renalis posterior*, Walter) arises from the last thoracic ganglion, and communicates sometimes with the nerve last described. After passing the diaphragm with the cord of the sympathetic, it ends in the renal plexus. Its place is frequently supplied by a branch of the small splanchnic nerve.

FUNCTIONAL DISTRIBUTION OF THE THORACIC PART OF THE SYMPATHETIC.

The thoracic portion of the gangliated cord receives most of the spinal fibres entering the sympathetic system (cf. p. 149). Only a small part of these end in the thoracic ganglia: the greater number pass either upwards into the neck or downwards into the abdomen. The fibres ascending to the neck arise from the upper thoracic nerves; they include the pupillo-dilator fibres, secretory fibres of the submaxillary gland, vaso-motor fibres of the head and neck, accelerator fibres of the heart, and others, all of which have been referred to in connexion with the cervical sympathetic (p. 158). In addition to these, the following groups have been demonstrated experimentally in the lower animals:

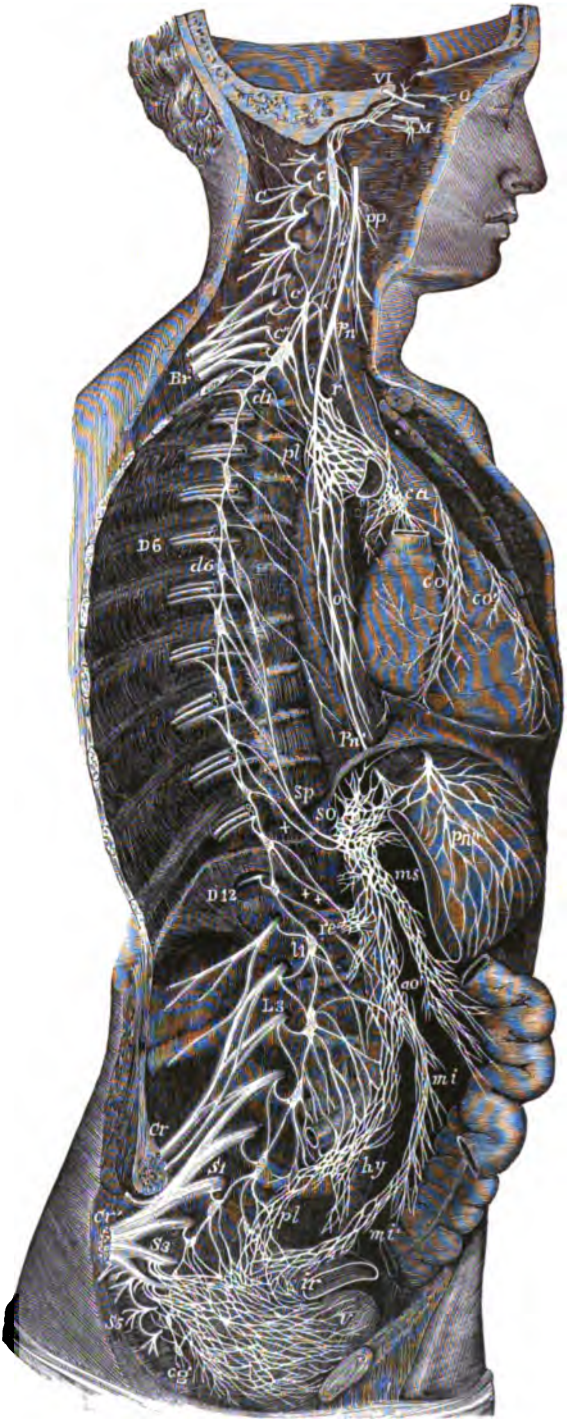

Fig. 95.—Diagrammatic view of the sympathetic cord of the right side, showing its connexions with the principal cerebrospinal nerves and the main pre-aortic plexuses. ¼.

Cerebrospinal nerves.—VI, a portion of the sixth cerebral nerve as it passes through the cavernous sinus, receiving two twigs from the carotid plexus of the sympathetic nerve; O, ciliary ganglion, connected by a twig with the cavernous plexus; M, connexion of the sphenopalatine ganglion by the large deep petrosal nerve with the carotid plexus; C, cervical plexus; Br, brachial plexus; D 6, sixth thoracic nerve; D 12, twelfth; L 3, third lumbar nerve; S 1, first sacral nerve; S 3, third; S 5, fifth; Cr, femoral nerve; Cr', sciatic; *pn*, vagus nerve in the lower part of the neck; *r*, its recurrent branch, winding round the subclavian artery.

Sympathetic cord.—*c*, superior cervical ganglion; *c'*, middle; *c''*, inferior: from each of these ganglia cardiac nerves (all deep on this side) are seen descending to the cardiac plexus; *d* 1, placed immediately below the first thoracic sympathetic ganglion; *d* 6 is opposite the sixth; *l* 1, first lumbar ganglion; *c g*, the terminal or coccygeal ganglion.

Pre-aortic and visceral plexuses.—*pp*, pharyngeal plexus; *pl*, posterior pulmonary plexus, spreading from the vagus on the back of the right bronchus; *ca*, on the aorta, the cardiac plexus, towards which, in addition to the cardiac nerves from the three cervical sympathetic ganglia, other branches are seen descending from the vagus and its recurrent branch; *co*, right or posterior, and *co'*, left or anterior coronary plexus; *o*, œsophageal plexus in long meshes on the gullet; *sp*, great splanchnic nerve; +, small splanchnic; + +, smallest splanchnic: the first and second of these are shown joining *so*, the cœliac plexus; the third descending to *re*, the renal plexus: connecting branches between the cœliac plexus and the vagus nerves are also represented; *pn'*, above the place where the right vagus passes to the posterior surface of the stomach; *pn''*, the left, distributed on the anterior surface of the cardiac portion of the organ: from the cœliac plexus large branches are seen surrounding the arteries of the cœliac axis, and descending to *ms*, the superior mesenteric plexus: opposite to this is an indication of the suprarenal plexus; below *re* (the renal plexus) the spermatic plexus is also indicated; *ao*, on the front of the aorta, marks the aortic plexus, formed by nerves descending from the cœliac and superior mesenteric plexuses and from the lumbar ganglia; *mi*, the inferior mesenteric plexus, surrounding the corresponding artery; *hy*, hypogastric plexus, placed between the common iliac arteries, connected above with the aortic plexus, receiving nerves from the lower lumbar ganglia, and dividing below into the right and left pelvic or inferior hypogastric plexuses; *pl*, right pelvic plexus: from this the nerves descending are joined by those from the plexus on the superior hæmorrhoidal vessels, *mi'*, by sympathetic nerves from the sacral ganglia, and by numerous visceral nerves from the third and fourth sacral spinal nerves, and there are thus formed the rectal, vesical, and other plexuses, which ramify upon the viscera from behind forwards, and from below upwards, as towards *ir*, and *v*, the rectum and bladder.

Vaso-constrictor fibres of the pulmonary vessels have been shown by Bradford and Dean, in the dog, to pass out of the spinal cord by the thoracic nerves from the second to the seventh (mainly, however, through the third, fourth, and fifth nerves), and to end in the ganglion stellatum.

Vaso-constrictor fibres of the limbs are connected with the vertebral ganglia. Those of the fore-limb are given off by the thoracic nerves, in the dog from the third to the eleventh (Bayliss and Bradford), in the cat from the fourth to the ninth (Langley). Those of the hind-limb are furnished, according to the same investigators, in the dog by the last three (11, 12, 13) thoracic and first three lumbar nerves, and in the cat by the last two or three thoracic and the first three or four lumbar nerves.

Secretory fibres to the sweat-glands of the fore-foot leave the thoracic nerves from the third or fourth to the ninth, and pass to the ganglion stellatum; while those of the hind-limb emerge by the last two thoracic and upper three lumbar nerves, and descend in the cord to the lower lumbar and upper sacral ganglia—in the cat (Langley).

Pilo-motor fibres in the cat pass from the lower nine or ten thoracic nerves, as well as the upper three or four lumbar, to the vertebral ganglia (Langley).

The splanchnic nerves contain:

Viscero-inhibitory fibres of the stomach and intestine.—According to Langley and Dickinson, they end in the ganglia of the cœliac plexus. They sometimes also contain viscero-motor fibres (J. L. Bunch).

Vaso-motor nerves of the abdominal blood-vessels.—The existence of vaso-constrictor fibres for the arteries of the alimentary canal in the splanchnic nerves is well established; and, according to Langley and Dickinson, these nerves also contain the vaso-dilator fibres of the same vessels: both sets of fibres end in the ganglia of the cœliac plexus. Vaso-constrictor fibres of the portal vein and its tributaries were originally demonstrated by Mall; according to Bayliss and Starling, in the dog, they are given off by the thoracic nerves from the third to the eleventh, but mainly from the fifth to the ninth. The nerves of the renal blood-vessels, both constrictor and dilator, are derived in the dog from the thoracic nerves from the sixth downwards, as well as (constrictors only) from the upper two lumbar nerves (Bradford): the renal vaso-motor fibres probably end in the ganglia of the renal plexus (Langley and Dickinson).

Constrictor fibres to the spleen (Schäfer and Moore).—These come off from the ventral roots of both sides along nearly the whole length of the thoracic cord and from some of the lumbar nerves.

Afferent fibres from the abdominal viscera.

The lowest part of the cord also contains:

Motor fibres to the muscular tissue of the rectum, proceeding from the lower thoracic nerves. Together with fibres from the upper one or two lumbar nerves, they pass by the aortic plexus to the inferior mesenteric ganglion.

LUMBAR PART OF THE GANGLIATED CORD.

In the lumbar region, the two gangliated cords approach one another more nearly than in the thorax. They are placed on the front of the bodies of the vertebræ, each lying along the inner margin of the psoas muscle; and that of the right side is partly covered by the vena cava, that of the left by the aorta.

The ganglia are small, and of an oval shape. They are commonly four in number, but occasionally their number is diminished, and they are then of larger size.

Connexion with spinal nerves.—In consequence of the greater distance at which the lumbar ganglia are placed from the intervertebral foramina, the branches of connexion with the spinal nerves are longer than in other parts of the gangliated cord. There are generally two connecting branches for each ganglion, but the number is not so uniform as it is in the chest; nor are those belonging to any one ganglion connected always with the same spinal nerve. The connecting branches accompany the lumbar arteries, and, as they cross the bodies of the vertebræ, are covered by the fibrous bands which give origin to the muscular fibres of the psoas.

The branches of these ganglia are uncertain in their number. Some join the plexus on the aorta; others descending go to form the hypogastric plexus.

Several filaments are distributed to the vertebræ and the ligaments connecting them.

FUNCTIONAL DISTRIBUTION OF THE LUMBAR SYMPATHETIC.

Spinal fibres pass into the sympathetic from the upper one or two lumbar nerves, and others descend in the cord from the lower thoracic nerves. For the most part they form a continuation of groups of fibres which have been noticed in the account of the thoracic sympathetic, including vaso-constrictor and secretory nerves of the hind-limb, pilo-motor fibres, vaso-constrictor fibres of the abdominal vessels, and motor fibres of the circular muscle, with inhibitory fibres of the longitudinal muscle of the rectum.

Arising from the lumbar nerves only are the following:

Vaso-motor nerves of the penis.—The *vaso-constrictor fibres* probably pass from the upper lumbar nerves into the sympathetic cord, whence they are mainly continued by pale fibres through grey rami communicantes to the pudendal nerve; but it is stated by François-Franck that some constrictor fibres run through the inferior mesenteric ganglion to the hypogastric plexus, and that these are accompanied by a part of the *vaso-dilator fibres* of the penis.

Motor fibres to the bladder, passing by the aortic plexus to the inferior mesenteric ganglion, and thence through the hypogastric and pelvic plexuses, to supply the circular muscle, including the sphincter. Associated with these there are probably inhibitory fibres of the longitudinal muscle. There is, however, considerable variation in the nerve-supply in different animals.[1]

Motor fibres to the uterus, taking a similar course to the foregoing.

Motor fibres to the vas deferens in the male, or to the round ligament of the uterus in the female, were found by Sherrington in the monkey leaving the cord by the ventral roots of the second and third lumbar nerves (corresponding to the first and second lumbar of man), and passing to their destination through the genital branch of the genito-femoral nerve.

SACRAL PART OF THE GANGLIATED CORD.

Over the sacrum, the gangliated cord of the sympathetic nerve is much diminished in size, and gives but few branches to the viscera. Its position on the front of the sacrum is along the inner side of the anterior sacral foramina; and, like the two series of those foramina, the right and left cords approach one another in their progress downwards. The upper end of each is united to the last lumbar ganglion by a single or a double interganglionic cord; and at the lower end they are connected by means of a loop, in which a single median ganglion, *ganglion impar* or *coccygeal ganglion,* placed on the fore-part of the coccyx, is often found. The sacral ganglia are usually four in number; but the variation both in size and number is more marked in these than in the thoracic or lumbar ganglia.

Variety.—In one instance the cord was found terminating at the second sacral nerve.[2]

Connexion with spinal nerves.—From the proximity of the sacral ganglia to the spinal nerves at their emergence from the foramina, the communicating branches are very short: there are often two for one ganglion, and these are in some cases connected with different sacral nerves. The coccygeal nerve communicates with the last sacral, or the coccygeal ganglion.

Branches.—The branches proceeding from the sacral ganglia are much smaller than those from other ganglia of the cord. They are for the most part expended on the front of the sacrum, and join the corresponding branches from the opposite side. Some filaments from one or two of the upper ganglia enter the pelvic plexus, while others go to form a plexus on the middle sacral artery. From the loop connecting the two cords filaments are given to the coccyx and to the ligaments about it, and to the coccygeal gland.

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[1] See on this subject Elliott, Journ. Physiol. xxxv. 1907.

[2] E. Fawcett, Journ. Anat. xxix. 329.

FUNCTIONAL DISTRIBUTION OF THE SACRAL SYMPATHETIC.

There are no spinal fibres passing from the sacral nerves to the sympathetic cord, but the latter contains medullated fibres which descend from the lumbar region and terminate in the sacral ganglia. These fibres include vaso-constrictor and secretory fibres of the hind-limb, and the pilo-motor fibres of the hindmost part of the body and the tail in the cat (Langley).

The **visceral branches of the sacral nerves** (*pelvic splanchnics*, Gaskell) are equivalent to white rami communicantes (p. 151), but they pass directly from the second, third, and fourth sacral nerves into the pelvic plexuses, from which they enter the plexuses of the pelvic viscera. They comprise:

Motor and inhibitory fibres to the muscular tissue of the rectum.

The **chief motor fibres of the bladder**, distributed probably to the longitudinal muscle.

Motor fibres of the uterus.

Vaso-dilator fibres of the penis (*nervi erigentes*).

Secretory fibres of the prostate gland.

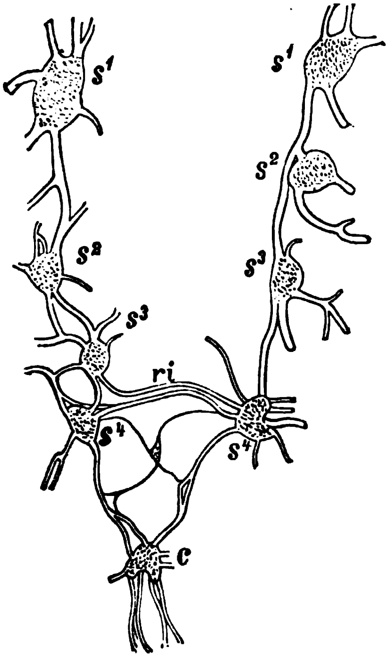

FIG. 96.—SACRAL PORTION OF THE SYMPATHETIC CORDS OF AN INFANT, SLIGHTLY ENLARGED. (Rauber.)

s 1–*s* 4, sacral ganglia; *c*, coccygeal ganglion, showing indications of its origin by the fusion of two ganglia, and sending downwards branches which run with the middle sacral artery; *ri*, interfunicular branches uniting the ganglia of the two sides; below these is seen a small interfunicular ganglion.

THE GREAT PLEXUSES OF THE SYMPATHETIC.

The **great prevertebral plexuses** comprise three large aggregations of nerves, or nerves and ganglia, situated in front of the spine, and occupying positions respectively in the thorax, the abdomen, and the pelvis. They are median in position, and are named respectively cardiac abdominal aortic, and hypogastric. These plexuses receive branches from the cerebrospinal nerves, as well as from both the gangliated cords, and they constitute centres from which the viscera are supplied with nerves.

Cardiac Plexus.

This plexus receives the cardiac branches of the cervical ganglia and those of the vagus nerves, and from it proceed the nerves which supply the heart, besides some offsets which contribute to the nervous supply of the lungs. It lies against the aorta and pulmonary artery, where these vessels are in contact, and in its network are distinguished two parts, the superficial and the deep cardiac plexuses, the deep plexus being seen behind the vessels, and the superficial more in front, but both being closely connected. The branches pass from these plexuses chiefly forwards in two bundles, accompanying the coronary arteries.

Superficial cardiac plexus.—The superficial cardiac plexus (fig. 95) lies in the concavity of the arch of the aorta, between the ligament of the ductus arteriosus and the right branch of the pulmonary artery. In it the superficial or upper cardiac nerve of the sympathetic of the left side terminates, either wholly or in part, together with the lower cervical cardiac branch of the left vagus nerve. In the superficial plexus a small ganglion, the *ganglion of Wrisberg*, is frequently found at the point of union of the nerves. Besides ending in the right coronary plexus, the superficial cardiac plexus furnishes laterally filaments along the pulmonary artery to the anterior pulmonary plexus of the left side.

Deep cardiac plexus.—The deep cardiac plexus, much larger than the superficial one, is placed behind the arch of the aorta, between it and the end of the trachea, and above the bifurcation of the pulmonary artery.

This plexus receives all the cardiac branches of the cervical ganglia of the sympathetic nerve, except the upper cardiac nerve of the left side. It likewise receives the cardiac nerves furnished by the vagus and by the recurrent laryngeal branch of that nerve, with the exception of the left inferior cervical cardiac nerve.

Of the branches from the *right side* of the plexus, the greater number descend in front of the right pulmonary artery, and join branches from the superficial part in the formation of the right coronary plexus; others, passing behind the right pulmonary artery, are distributed to the right auricle of the heart, and a few filaments are continued into the left coronary plexus.

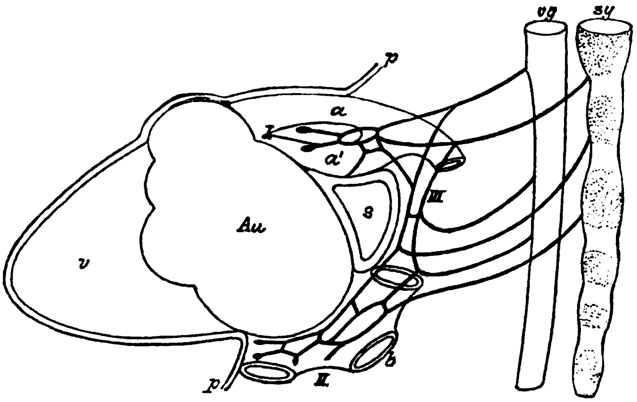

FIG. 97.—DIAGRAMMATIC REPRESENTATION OF THE CARDIAC PLEXUS OF THE HUMAN EMBRYO. (W. His, jun.)

a, aorta; *a'*, pulmonary artery; *b*, atrium, with the orifices of the veins; *Au*, auricle proper; *v*, ventricle; *vg*, vagus; *sy*, cord of sympathetic; *p*, *p*, pericardium; *s*, transverse sinus of pericardium; I, bulbar plexus; II, atrial plexus; III, intermediate plexus.

On the *left side*, a few branches pass forwards by the side of the ligamentum arteriosum to join the superficial cardiac plexus, and others descend to the left auricle; but the great majority end in the left coronary plexus.

The deep cardiac plexus sends filaments to the anterior pulmonary plexus on each side.

Coronary plexuses.—The *right* or *posterior coronary plexus* is derived from both the superficial and deep cardiac plexuses, the filaments by which it arises embracing the root of the aorta. It accompanies the right coronary artery on the heart, sending its branches upwards and downwards to the auricle and ventricle.

The *left* or *anterior coronary plexus* is larger than the right, and is derived mainly from the left half of the deep cardiac plexus. Being directed forwards between the pulmonary artery and the left auricular appendage, it reaches the left coronary artery, and subdivides into two principal portions which accompany the primary divisions of that vessel.

Nervous filaments ramify in great number under the epicardium, especially on the ventricular portion of the heart. They are not so easily distinguished in man as in some animals. In the heart of the calf or the lamb they are distinctly seen without dissection, running in lines which cross the muscular fibres obliquely. Microscopic ganglia occur on the nerves of the auricles, and in the course of the coronary plexuses, but they are absent from the offsets to the ventricular wall.

From the embryological investigations of W. His, jun., it appears that the ascending aorta, the pulmonary trunk, and the ventricles of the heart are supplied by the upper cardiac nerves, while the auricles receive branches arising at a lower level. The earliest of the cardiac nerves to be developed are branches from both vagus and sympathetic of each side to the arterial bulb, which appear about the end of the fourth or the beginning of the fifth week of fœtal life, and make their way between the aorta and the pulmonary trunk, where they form the *bulbar plexus.* In the seventh week other nerves are found passing from the vagi lower down to the back of the auricles, and forming there the *atrial plexus,* which also receives sympathetic branches through the following plexus. The bulbar and atrial plexuses are connected by branches which descend from the former behind the transverse sinus of the pericardium, and are joined by offsets of both vagi, the left recurrent nerve, and the sympathetic cords, the whole constituting the *intermediate plexus.* All of these branches contain numerous ganglion-cells of sympathetic nature, which travel downwards with the growth of the nerves. In the course of the third month the coronary nerves are developed from the bulbar plexus, and offsets of the atrial plexus spread over the auricles. In the definitive state therefore the bulbar plexus is represented by the superficial cardiac plexus and a part of the deep cardiac plexus, with their coronary offsets, the intermediate plexus by the remainder of the deep cardiac plexus, and the atrial plexus by the network on the auricles. The distribution of the ganglia in the adult heart corresponds to the extent of these plexuses.

Abdominal Aortic Plexus.

The *abdominal aortic plexus* is situated in front and at the sides of the abdominal aorta, and from it secondary plexuses are prolonged on the branches of the abdominal aorta to the viscera of the abdomen. The plexus is best developed above, and it is continued below over the common iliac arteries to the hypogastric plexus.

The upper portion is placed behind the stomach, and in front of the aorta and the pillars of the diaphragm. Surrounding the origin of the cœliac axis and the superior mesenteric artery, it occupies the interval between the suprarenal bodies, and extends downwards behind the pancreas. The plexus consists of nervous cords, with several ganglia of various sizes connected with them. The large and small splanchnic nerves on both sides, and some branches of the vagus, terminate in it. The branches given off from it are very numerous, and accompany the arteries arising from the upper part of the abdominal aorta, constituting so many secondary plexuses on the vessels. Thus, diaphragmatic, cœliac, superior mesenteric, and other plexuses are recognised, which follow the corresponding arteries.

The plexus contains several ganglia (*ganglia cœliaca*); and by the size of these bodies it is distinguished from the other prevertebral plexuses. The two principal ganglionic masses, named *semilunar,* though they have often little of the form the name implies, occupy the upper and outer part of the plexus, one on each side, and are placed close to the suprarenal bodies, by the side of the cœliac and the superior mesenteric arteries. At the upper end, which is expanded, each ganglion receives the great splanchnic nerve. The lower part of the ganglionic mass, lying over the root of the renal artery, is commonly more or less detached from the rest, and is distinguished as the *aortico-renal ganglion*; it is joined by the small splanchnic nerve, and gives origin to the greater part of the renal plexus. Another part, lying below and to the right of the origin of the superior mesenteric artery, is named the *superior mesenteric ganglion.*

The lower part of the plexus consists, for the most part, of two lateral cords, which are connected above with the semilunar ganglia and renal plexuses, and extend downwards on the sides of the aorta, below the origin of the superior mesenteric, meeting in several communicating branches over the front of the aorta. The cords receive branches from some of the lumbar ganglia, and at the spots where these join there are often small ganglionic enlargements, which are more distinct in the infant. Several filaments pass to the root of the inferior mesenteric artery to form the plexus on that vessel, and in connexion with these is the *inferior mesenteric ganglion*, placed below the origin of the artery. The lower part of the plexus, to which the name aortic plexus is often restricted, furnishes the inferior mesenteric plexus and part of the spermatic, gives some filaments to the lower vena cava, and ends below in the hypogastric plexus.

Phrenic (diaphragmatic) plexus.—The nerves composing this plexus are derived from the upper part of the semilunar ganglion, and are larger on the right than on the left side. Accompanying the arteries along the lower surface of the diaphragm, the nerves sink into the substance of the muscle. They furnish some filaments to the suprarenal body, and join with the spinal phrenic nerves.

At the right side, on the under surface of the diaphragm, and near the suprarenal body, there is a small ganglion (*phrenic ganglion*) which marks the junction between the phrenic nerves of the spinal and sympathetic systems. From this small ganglion filaments are distributed to the vena cava, the suprarenal body, and the hepatic plexus. On the left side the ganglion is wanting.

Suprarenal plexus.—The suprarenal nerves issue from the cœliac plexus and the outer part of the semilunar ganglion, some filaments being added from the diaphragmatic plexus and one of the splanchnic nerves. They are short, but numerous in comparison with the size of the suprarenal body, which they enter on its inner and posterior part. These nerves consist in great part of white fibres, and are beset with minute ganglia.

Renal plexus.—The nerves forming the renal plexus emanate for the most part from the aortico-renal ganglion, but some are added from the abdominal aortic plexus. The renal plexus also receives the termination of the smallest, and sometimes filaments from the small splanchnic nerve, as well as a branch from the first lumbar ganglion. The nerves of the plexus are mostly grey, and in their course along the renal artery ganglia of different sizes (*renal ganglia*) are formed on them. Lastly, dividing with the branching of the vessel, the nerves follow the renal arteries into the substance of the kidney. On the right side some filaments are furnished to the vena cava, behind which the plexus passes with the renal artery; and on both sides offsets pass to the spermatic plexus, and a filament to the ureter.

Spermatic and ovarian plexuses.—The spermatic plexus commences in the renal, but receives in its course along the spermatic artery an accession from the aortic plexus, in which a small *spermatic ganglion* is often formed at the place where these branches arise. Continuing downwards to the testis, the spermatic nerves are connected with others which accompany the vas deferens and its artery from the pelvis.

In the female, the *ovarian plexus*, like the artery, is distributed to the ovary and the uterus.

Cœliac plexus.—This plexus is of large size, and is continuous with the upper and fore-part of the abdominal aortic plexus. It surrounds the cœliac axis in a kind of fenestrated sheath, and subdivides, with the artery, into coronary, hepatic, and splenic plexuses, the branches of which form communications corresponding with the arches of the arterial anastomosis. The plexus receives on the left side a considerable offset from the right vagus nerve.

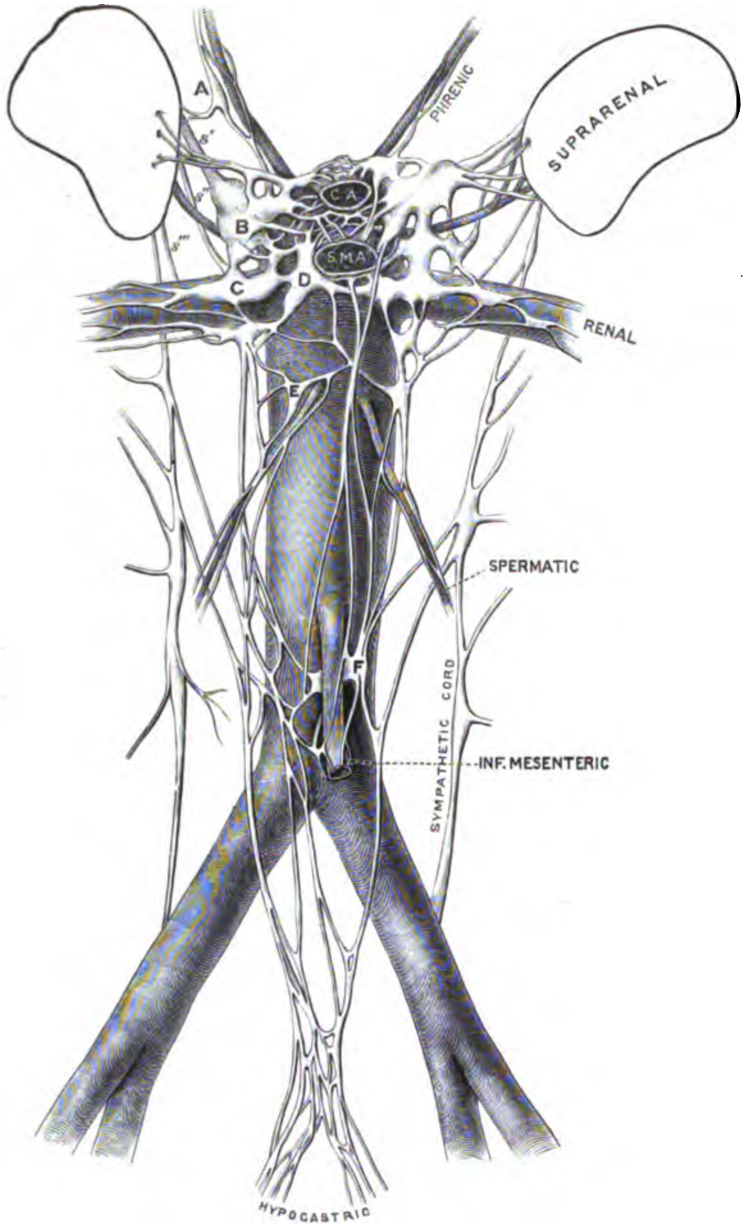
A
s''
s'
s'''
B
C
D
C.A.
S.M.A.
PHRENIC
SUPRARENAL
RENAL
E
SPERMATIC
F
SYMPATHETIC CORD
INF. MESENTERIC
HYPOGASTRIC

FIG. 98.—ABDOMINAL AORTIC PLEXUS, WITH THE LUMBAR PORTION OF THE SYMPATHETIC CORDS, IN THEIR RELATIONS TO THE AORTA, ETC. (G. D. Thane.)

C.A., cœliac axis, and S.M.A., superior mesenteric artery, both cut close to their origin; surrounding them is the cœliac plexus; on the aorta below the renal arteries is the lower part of the abdominal aortic plexus; s', great, s'', small, and s''', smallest splanchnic nerves; A, phrenic ganglion; B, semilunar ganglion; C, aortico-renal ganglion; D, superior mesenteric ganglion; E, spermatic ganglion; F, inferior mesenteric ganglion.

The *coronary plexus* is placed with its artery along the small curvature of the stomach, and unites with the nerves which accompany the pyloric artery, as well as with branches of the vagus nerves. The nerves of this plexus enter the coats of the stomach, after running a short distance beneath the peritoneum.

The *hepatic plexus*, the largest of the three divisions of the cœliac plexus, ascends with the hepatic vessels and the bile-duct, and, entering the substance of the liver, ramifies on the branches of the portal vein and the hepatic artery. Offsets from the left vagus nerve join the hepatic plexus at the left side of the vessels. From this plexus filaments pass to the right suprarenal plexus, as well as other secondary plexuses which follow the branches of the hepatic artery. Thus there is a *cystic plexus* to the gall-bladder; and there are *pyloric*, right *gastro-epiploic*, and *pancreatico-duodenal plexuses*, which unite with coronary, splenic, and mesenteric nerves.

The *splenic plexus* (*plexus lienalis*), continued on the splenic artery and its branches into the substance of the spleen, is reinforced at its beginning by branches from the left semilunar ganglion, and by filaments from the right vagus nerve. It furnishes the *left gastro-epiploic* and *pancreatic plexuses*, which course along the corresponding branches of the splenic artery, and, like the vessels, are distributed to the stomach and pancreas.

Superior mesenteric plexus.—The plexus accompanying the superior mesenteric artery, whiter in colour and firmer than any of the preceding offsets, is mainly given off from the lower part of the cœliac plexus and the superior mesenteric ganglion, but it also receives fibres from the right vagus nerve at its junction with the cœliac plexus. Surrounding the trunk of the superior mesenteric artery, it divides into secondary plexuses which agree in name and distribution with the branches of that vessel. In their progress to the intestine some of the nerves quit the arteries which first supported them, and are directed forwards in the intervals between the vessels. As they proceed they divide, and unite with lateral branches, like the arteries, but without the same regularity; they finally pass upon the intestine along the line of attachment of the mesentery.

Inferior mesenteric plexus.—This plexus is derived principally from the left lateral part of the aortic plexus, and closely surrounds with a network the inferior mesenteric artery. It distributes nerves to the descending iliac and pelvic portions of the colon, and assists in supplying the rectum. The nerves of this plexus, like those of the superior mesenteric plexus, are firm in texture and of a whitish colour.

The highest branches (those on the left colic artery) are connected with the last branches (middle colic) of the superior mesenteric plexus, while others in the pelvis unite with offsets derived from the pelvic plexus.

On the branches of the cœliac and mesenteric plexuses Pacinian corpuscles are often present. They are very variable in number, and are not so numerous or regular in man as in the cat. Their most frequent seat is in the loose tissue behind the pancreas.

Hypogastric Plexus.

The hypogastric plexus, the assemblage of nerves destined for the supply of the viscera of the pelvis, lies, invested in a sheath of dense connective tissue, in the interval between the two common iliac arteries. It is formed by the prolongations of the aortic plexus on each side, which receive considerable branches from the lumbar ganglia, and, after crossing the common iliac artery, interlace in the form of a flat plexiform mass placed in front of the lowest lumbar vertebra. The plexus contains no distinct ganglia. At the lower end it divides into two parts, which are directed downwards, one to each side of the pelvic viscera, and form the pelvic plexuses.

Pelvic plexus.—The pelvic or inferior hypogastric plexuses (fig. 95, *pl*), one on each side, are placed in the lower part of the pelvic cavity by the side of the rectum, and of the vagina in the female. The nerves, continued from the hypogastric plexus, enter into repeated communications as they descend, and form at the points of connexion small knots, which contain a little ganglionic matter. After descending some way, they become united with branches of the spinal nerves, as well as with a few offsets of the sacral ganglia, and the union of all constitutes the pelvic plexus. The spinal branches which enter into the plexus are furnished from the third and fourth sacral nerves, sometimes also the second. Small ganglia are formed at the places of union of the spinal nerves, as well as elsewhere in the plexus.

From the plexus so constituted, numerous nerves are distributed to the pelvic viscera. They correspond in great measure with the branches of the internal iliac artery, and vary with the sex; thus, besides hæmorrhoidal and vesical nerves, which are common to both sexes, there are nerves special to each—namely, in the male for the prostate, vesicula seminalis, and vas deferens; in the female for the vagina, uterus, ovary, and Fallopian tube.

The nerves distributed to the urinary bladder and the vagina contain a larger proportion of spinal fibres than those furnished to the other pelvic viscera.

Hæmorrhoidal plexus.—These slender nerves proceed from the upper part of the pelvic plexus. They join with the nerves (superior hæmorrhoidal) which descend with the inferior mesenteric artery, and penetrate the coats of the rectum.

Vesical plexus.—The nerves of the urinary bladder are very numerous. They are directed from the lower part of the pelvic plexus to the side and lower part of the bladder. At first these nerves accompany the vesical blood-vessels, but afterwards they leave the vessels, and subdivide into minute branches before perforating the muscular coat of the organ. The lower part of the ureter is also supplied by these nerves; and secondary plexuses are given in the male to the vas deferens and the vesicula seminalis.

The *nerves of the vas deferens* ramify round that tube, and communicate in the spermatic cord with the nerves of the spermatic plexus. Those furnished to the *vesicula seminalis* form an interlacement on the vesicula, and some branches penetrate its substance. Other filaments from the prostatic nerves reach the same structure.

Prostatic plexus.—The nerves of this plexus are of considerable size, and pass between the prostate gland and the levator ani. Some are furnished to the prostate and to the vesicula seminalis; and the plexus is then continued forwards to supply the erectile substance of the penis, where its nerves are named *cavernous*.

Cavernous nerves of the penis.—These are very slender, and difficult to dissect. Continuing from the prostatic plexus, they pass onwards beneath the subpubic arch and through the muscular structure connected with the membranous part of the urethra, to the dorsum of the penis. At the root of the latter, the cavernous nerves are joined by some short filaments from the pudendal nerve. Having distributed twigs to the fore-part of the prostate and the membranous part of the urethra, these nerves divide into branches for the erectile substance of the penis, as follows:

The *small cavernous nerves* perforate the fibrous covering of the corpus cavernosum near the root of the penis, and end in the erectile substance.

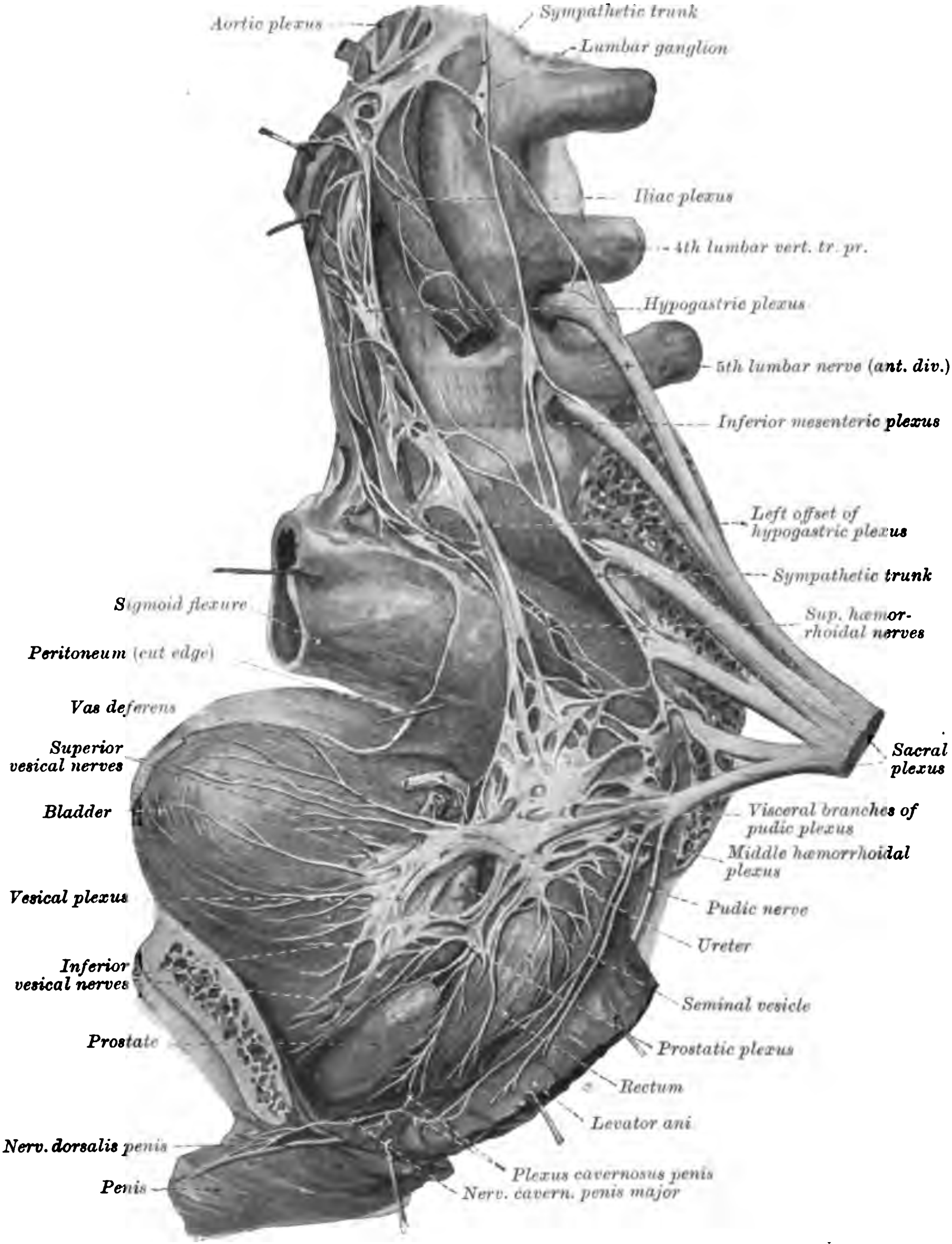
Aortic plexus
Sympathetic trunk
Lumbar ganglion
Iliac plexus
4th lumbar vert. tr. pr.
Hypogastric plexus
5th lumbar nerve (ant. div.)
Inferior mesenteric plexus
Left offset of hypogastric plexus
Sympathetic trunk
Sup. hæmorrhoidal nerves
Sigmoid flexure
Peritoneum (cut edge)
Vas deferens
Superior vesical nerves
Sacral plexus
Bladder
Visceral branches of pudic plexus
Middle hæmorrhoidal plexus
Vesical plexus
Pudic nerve
Ureter
Inferior vesical nerves
Seminal vesicle
Prostate
Prostatic plexus
Rectum
Levator ani
Nerv. dorsalis penis
Plexus cavernosus penis
Penis
Nerv. cavern. penis major

FIG. 99.—THE PELVIC SYMPATHETIC OF THE LEFT SIDE. (Spalteholz.)

The left half of the bony pelvis, with its muscles, is for the most part removed; the sacral plexus and levator ani are drawn aside.

The *large cavernous nerve* extends forwards on the dorsum of the penis and, dividing, gives filaments which penetrate the corpus cavernosum, and pass with or near the cavernous artery. As it continues onwards, this nerve joins with the dorsal branch of the pudendal nerve about the middle of the penis, and is distributed to the corpus cavernosum. Branches from the foregoing nerves reach the corpus spongiosum urethræ. The cavernous nerves are composed mainly of pale fibres.

Vaginal nerves.—The nerves furnished to the vagina leave the lower part of the pelvic plexus—that part with which the spinal nerves are more particularly combined. They are distributed to the vagina without previously entering into a plexiform arrangement; and they end in the erectile tissue on the lower and anterior part, and in the mucous membrane.

Nerves of the uterus.—These nerves are derived mainly from the lateral fasciculus prolonged to the pelvic plexus from the hypogastric plexus, but some filaments are also added from the third and fourth sacral nerves. They are directed upwards with the blood-vessels, between the layers of the broad ligament, along the side of the organ, and some slender filaments accompany the branches of the uterine artery, but the larger number of the nerves sink directly into the substance of the uterus, penetrating for the most part its neck and the lower portion of its body. They form connexions in the broad ligament with the ovarian nerves, and the fundus of the uterus also receives an offset from that plexus. Numerous small ganglia are contained in the plexus by the side of the neck of the uterus, and a cluster of these constitutes the *ganglion cervicale* of Frankenhäuser. They appear to be absent in the muscular substance of the organ. One branch continued directly from the common hypogastric plexus reaches the hinder surface of the body of the uterus above the rest; and a nerve from the same source ascends to the Fallopian tube.

The *nerves of the gravid uterus* have been frequently investigated, with a view to discover if they become enlarged along with the increase in size of the organ. It is ascertained that the increase which takes place is confined, for the most part, to the thickening of the fibrous envelopes of the nerves; but it is stated also that fibres furnished with a medullary sheath, which in the unimpregnated state of the uterus lose that sheath as they proceed to their distribution, in the impregnated condition of the uterus continue to be surrounded with it as they run between the muscular fibres (Kilian).

ORGANS OF THE SENSES.

In this Part will be described the organs of sight, hearing, and smell, and also the taste-buds which are found on the tongue and other parts endowed with the sense of taste. The terminations of sensory nerves in the skin and elsewhere are described along with the general Histology, and will here only be briefly alluded to in reviewing the whole subject of the ending of nerves of special sense.

THE EYE.

The organ of vision, strictly speaking, consists only of the ball or globe of the eye; but connected with the eyeball externally are muscles, nerves, and blood-vessels, elsewhere described, as well as other parts specially adapted for its protection, such as the eyelids and lacrymal apparatus, of which an account will first be given.

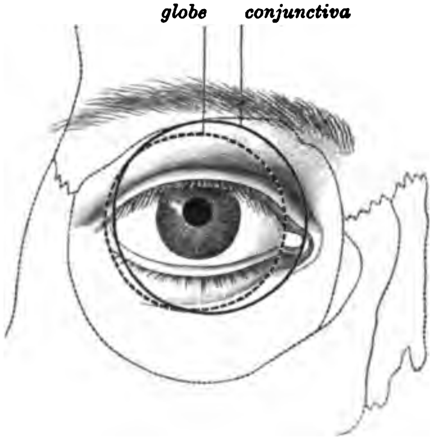

FIG. 100.—RIGHT EYE FROM BEFORE, WITH THE CONTOURS OF THE EDGE OF THE ORBIT, OF THE GLOBE, AND OF THE PERIPHERY OF THE CONJUNCTIVAL SAC OUTLINED IN. (Merkel and Kallius.)

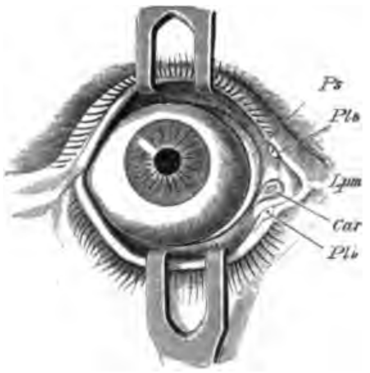

FIG. 101.—FRONT VIEW OF THE RIGHT EYE, WITH THE EYELIDS DRAWN APART BY BLUNT HOOKS. (Merkel.)

Ps, plica semilunaris; *Pls*, *Pli*, punctum lacrimale (sup. et inf.); *Car*, caruncula lacrimalis; *Lpm*, mesial palpebral ligament.

THE EYELIDS AND CONJUNCTIVA.

The eyelids (*palpebræ*) are movable folds of integument, strengthened towards their margins by a thin lamina of dense fibrous tissue (*tarsus*). Each eyelid has two surfaces, an anterior and a posterior, and a free edge, about 3 mm. thick, directed towards that of the other eyelid. The anterior surface is formed by skin; a mucous membrane (*conjunctiva*) lines the posterior surface, and is reflected thence on the front of the eyeball. The line of reflection is termed the *fornix conjunctivæ*.

The upper lid is larger and more movable than the lower, all the transparent part of the globe being covered by it when the eye is closed; it is chiefly by the elevation of this lid that the eye is opened, the movement being effected by a muscle (*levator palpebræ*) devoted exclusively to this purpose. At the outer and inner angles (*canthi*) of the eye the eyelids are united. The interval between the edges of the two eyelids is termed the *rima palpebraris*. The transverse diameter of the rima, measured between the canthi, varies in different individuals, averaging about 28 mm. (Fuchs), and, according to its extent, gives the appearance of a larger or a smaller eye, the size of the globe being nearly the same in all. The greater part of the edge of each eyelid is flattened and angular, but towards the inner canthus it is rounded off for a short space, and at the same time changes its direction, so that a rounded bay is here left between the two eyelids (figs. 100, 101); this bay has been termed the lacrymal reservoir (*lacus lacrimalis*); at this point there is seen on each lid a slight elevation (*papilla lacrimalis*), the apex of which is pierced by the aperture (*punctum*) of a small canal (*canaliculus lacrimalis*) which serves to convey away the fluid which moistens the conjunctiva (fig. 101, *Pli*, *Pls*). (See also figs. 109, 110, and 111.)

In the greater part of their extent the lids are applied to the surface of the eyeball; but at the inner canthus, at the so-called lacrymal lake, there intervenes a vertical fold of conjunctiva, the *plica semilunaris* (fig. 101, *Ps*), which rests on the eyeball; whilst occupying the recess of the angle at the border of this fold is a spongy-looking reddish elevation (*caruncula lacrimalis*, *Car*) formed by a small isolated portion of skin containing a few large modified sweat-glands, as well as a group of sebaceous glands which open into the follicles of very fine hairs. There is further found in it a small amount of plain muscular tissue (H. Müller), as well as some cross-striated muscular fibres.[1]

The plica semilunaris is the rudiment of the third eyelid (*membrana nictitans*) found in many animals; and in some animals, and occasionally in man, the caruncula lacrimalis retains its connexion with the skin at the inner canthus. The muscular tissue of the nictitating membrane of animals, and presumably, therefore, of the semilunar fold of man, receives its nerve-supply through the cervical sympathetic. In many animals, and occasionally in man (in the negro constantly, according to Giacomini), the plica semilunaris contains a plate of hyaline cartilage. It also has a few plain muscular fibres.

Structure of the lids.—The skin covering the eyelids is thin, freely movable, and covered with fine downy hairs (fig. 102, *i*, *i*). These are provided with sebaceous follicles; small sweat-glands are also present. At the line of the eyelashes the skin joins the conjunctival mucous membrane which lines the inner surface of the lids. The cutis vera contains a number of ramified pigment-cells, and pigment is also frequently found in the Malpighian layer of the epidermis, especially near the inner angle of the lids. Beneath the skin is a quantity of very loose connective tissue, entirely free from fat and containing the fasciculi of the orbicularis palpebrarum muscle (*b*), and beneath the mucous membrane on the posterior surface is the lamina of dense connective tissue, before mentioned, known as the tarsus (*e*), or, from its consistence, the tarsal cartilage, which thins off near the attached margin of the eyelid into the palpebral fascia connecting it with the margin of the orbit. On the deep or ocular surface of the tarsi are imbedded the Meibomian glands (*f*). In the upper eyelid there is, in addition, the insertion of the levator palpebræ superioris, attached to the anterior surface of the tarsus by fibrous tissue and smooth muscular tissue (see next page), and further sending a well-marked flat tendinous expansion, the bundles of which pass between the bundles of the orbicularis palpebrarum muscle, and are attached to the skin of the middle of the eyelid (fig. 106). There is nothing corresponding to this in the lower lid, but the inferior rectus and oblique muscles send strands of fibrous tissue forwards to be attached to the tarsus and palpebral ligament.

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[1] On the structure of the caruncula, see Stieda, Arch. f. mikr. Anat. xxxvi. 1890.

The *orbicularis muscle* (palpebral portion) is attached to the skin by connective tissue, but glides loosely on the tarsi. A marginal fasciculus lies within the line of the eyelashes, separated by the bulbs of the lashes from the other fibres, and constituting the *ciliary bundle* (fig. 102, *b'*). The fibres of the muscle are very small, and pale in colour. They are attached mesially and laterally to the palpebral ligaments (see below).

The *tarsi* are two thin elongated plates formed of dense connective tissue, without any intermixture of cartilage-cells. They are placed one in each lid, to which they give shape and firmness. The upper one, the larger, is half oval in form, being broader near the centre and narrowing towards the angles of the lids. The lower is thinner, much narrower, and more nearly of a uniform breadth throughout. Their free edges, which are straight, are thicker than any other part. At the inner canthus they are fixed to the nasal process of the maxillary bone by the *mesial palpebral ligament*; and at the outer angle are attached to the malar bone by the *lateral palpebral ligament* (see below). Groups of fat-cells are found in the tarsus both near its attached border and scattered over its anterior surface (Merkel).

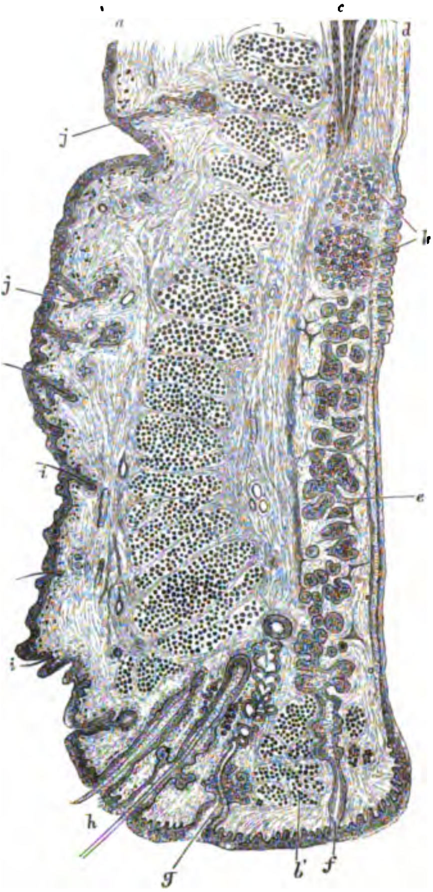

Fig. 102.—Vertical section through the upper eyelid, human. Magnified. (After Waldeyer.)

a, skin; *b*, orbicularis; *b'*, ciliary bundle; *c*, involuntary muscle of eyelid; *d*, conjunctiva; *e*, tarsus; *f*, Meibomian gland; *g*, sebaceous gland near eyelashes, with modified sweat-gland opening with it; *h*, eyelashes; *i*, small hairs in outer skin; *j*, sweat-glands; *k*, posterior tarsal glands.

The *palpebral fascia* is a fibrous membrane placed beneath the orbicularis muscle, attached on the one hand to the margin of the orbit, and on the other prolonged towards the adjacent border of each tarsus. In the lower lid its tissue is continuous with that of the tarsus, but in the upper lid it blends with the tendon of the levator palpebræ. The membrane is thicker at the outer part of the orbit, where it forms the lateral (external) palpebral ligament (fig. 104). The mesial (internal) palpebral ligament, to which the fibres of the orbicularis palpebrarum are also attached, is not formed from the general palpebral fascia, but lies altogether in front of it. The palpebral fascia extends downwards from the crista lacrimalis posterior, between the osseous boundary of the nasal duct and the origin of the inferior oblique muscle, to reach the lower border of the orbit (Merkel).

The palpebral fascia thus acts as a kind of fibrous septum between the cutaneous and the conjunctival parts of the eyelid at its attached border: it was therefore termed the *septum orbitale* by Henle. It is perforated above the internal tarsal ligament by the termination of the ophthalmic artery, with a considerable anastomotic vein between the superior ophthalmic and the angular, and its attachment to the supra-orbital margin is interrupted internal to the centre by the passage of the supra-orbital nerve (in one or two pieces) with the accompanying artery.

On the ocular surface of each lid are seen parallel vertical rows of what, seen through the conjunctival mucous membrane, look like yellow granules. There are twenty to thirty of these rows in the lower lid, somewhat more in the upper lid; they are the *Meibomian* or *tarsal glands* (figs. 102, 103). These are long sebaceous glands, imbedded in the tarsi; they open on the free margin of the lids by minute orifices, generally one for each. The glands consist of nearly straight tubes, closed at the end, with numerous small cæcal appendages projecting from the sides. Sometimes they are bent round at the blind end. The mouths of the tubes are lined by stratified epithelium continuous with that of the skin; but the ducts and the glandular recesses have a lining of cubical epithelium filled with the fatty secretion. According to Colosanti, the glands have a basement membrane, and a muscular layer outside this: he further describes a network of fine nervous fibrils amongst the epithelium-cells.

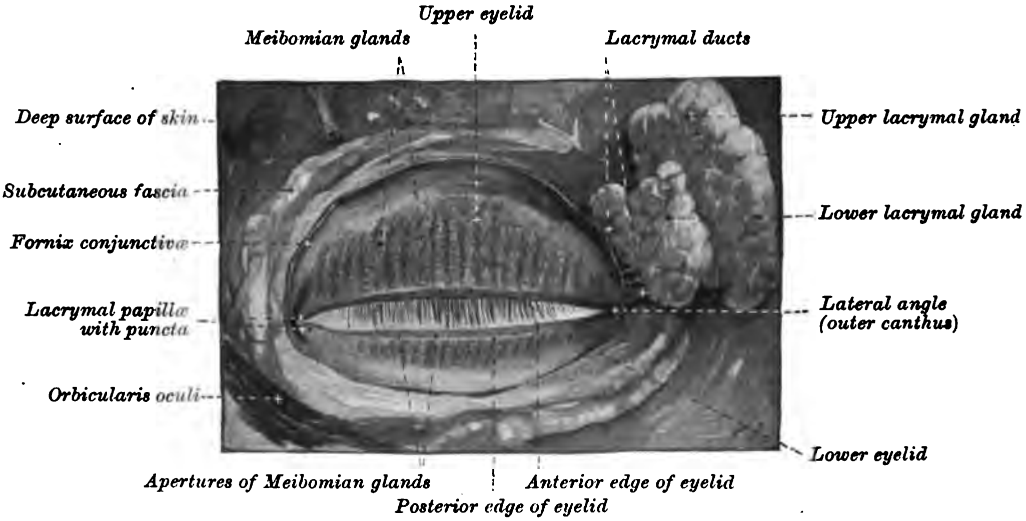
Upper eyelid
Meibomian glands
Lacrymal ducts
Deep surface of skin
Upper lacrymal gland
Subcutaneous fascia
Lower lacrymal gland
Fornix conjunctivæ
Lacrymal papillæ with puncta
Lateral angle (outer canthus)
Orbicularis oculi
Lower eyelid
Apertures of Meibomian glands
Anterior edge of eyelid
Posterior edge of eyelid

FIG. 103.—EYELIDS OF RIGHT SIDE AS SEEN FROM BEHIND, AFTER REMOVAL OF THE GLOBE (Spalteholz.)

A layer of unstriped muscular tissue is contained in each eyelid (H. Müller): that of the upper (fig. 102, *c*; fig. 106) arising from the under surface of the levator palpebræ, that of the lower from the neighbourhood of the inferior oblique muscle, and each being inserted near the attached margin of the tarsus. According to Henle, some of the fibres have a transverse course.

The *eyelashes* (*cilia*) are strong short curved hairs, arranged in two or more rows along the margin of the lids, at the line of union between the skin and the conjunctiva. The upper lashes are fully twice as numerous [1] and are longer than the lower; they are curved in an opposite direction in the two lids, so that their convexities are directed towards one another. The edge of the lid, in which the follicles of the eyelashes are set, is composed of dense fibrous tissue, somewhat similar in nature to that of the tarsus, with which it is, in fact, in the upper lid continuous (Merkel). The hair-follicles are of some length (1·5 to 2·5 mm.), penetrating obliquely from the outer edge of the lid nearly to the tarsi.

Near the inner canthus the hairs are weaker and more scattered. Immediately within the eyelashes, between them and the ciliary bundle of the orbicularis, is a row of large modified sweat-glands (*glands of Moll*), which sometimes open into the mouths of large sebaceous glands (fig. 102, *g*).

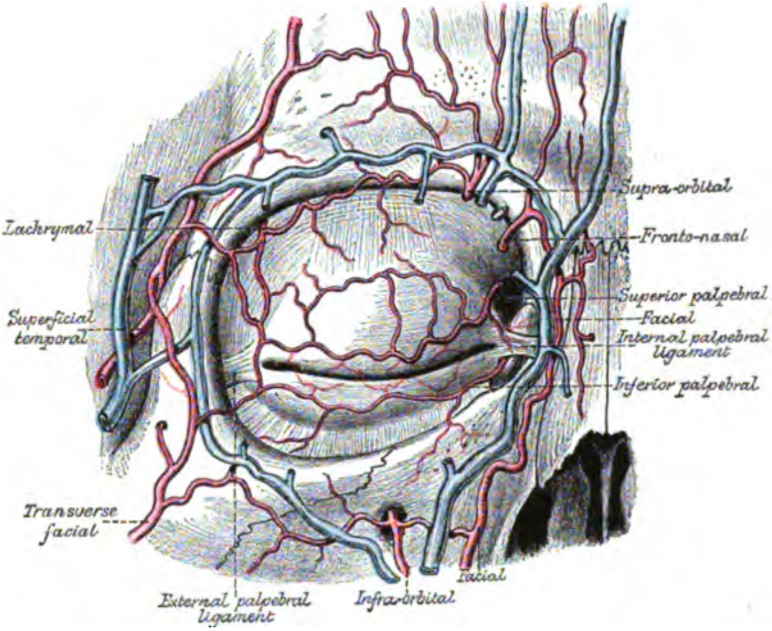

FIG. 104.—DISSECTION SHOWING THE ARTERIES AND VEINS OF THE EYELIDS. (After Testut.)

The *conjunctiva* consists of palpebral part (*conjunctiva palpebrarum*), with which may be included the plica semilunaris and caruncula, and ocular part (*conjunctiva bulbi*), in which may be distinguished the scleral and corneal portions. The epithelium varies at different parts; that of the eyelids is columnar, but near the skin and cornea it shades off into stratified.

The *palpebral portion* of the conjunctiva is thicker and more vascular than the rest of the membrane. It has many elastic fibres. Although closely united to the tarsi, it exhibits, except in the young, numerous small creases or folds, which are visible with a lens. A layer of small tubulo-racemose glands (*posterior tarsal*) is found on the ocular surface of the lids, immediately under the conjunctiva, beyond the blind ends of the Meibomian glands (fig. 102, *k*). Their ducts open near the line of reflection of the conjunctiva.

Harderian gland.—All animals which possess a well-developed membrana nictitans have also, situated at the mesial angle of the eye, a special gland, the duct of which opens beneath

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[1] Donders, Arch. f. Ophth. 1858, gives 140–150 for the upper eyelid and 50–75 for the lower. Mühly (Diss. Basel, 1879) found that there were sometimes as many as 200 in the upper lid and 100 in the lower.

the third eyelid. The gland has a racemose structure, and secretes a milky mucin-containing fluid, thus differing from the serous-secreting lacrymal. It is not found in Primates, unless in an extremely vestigial form. Some animals (*e.g.* rabbit) possess an infra-orbital gland also.[1]

The ocular portion.—The conjunctiva changes its character at the line of reflexion from the eyelids, becoming thinner and devoid of glands. In many animals, including man, there are goblet-cells among the other cells of the epithelium.[2] It is loosely connected to the sclerotic coat of the eyeball by submucous tissue, except near the cornea, where it forms a sharp edge called the limbus conjunctivæ, and is firmly adherent to the subjacent sclerotic. Over the cornea it becomes transparent and is represented only by the epithelium of the cornea, in connexion with which it will be described.

The portion of the conjunctiva reflected from the eyelids on to the eyeball is very lax and easily thrown into folds so that the movements of the eyeball are not impeded by traction on the palpebral conjunctiva.

Blood-vessels.—Blood is supplied to the eyelids mainly by the internal and external palpebral arteries; the former being derived from the ophthalmic artery and the latter from its branch, the lacrymal. The *internal* or *mesial palpebral* are usually the larger, and consist of two vessels, a superior and an inferior, one for each lid, which they reach by piercing the palpebral fascia, one a little above and the other just below the mesial palpebral ligament (fig. 104). In the eyelid each vessel runs with a tortuous course near the free border between the tarsus and the bundles of the orbicularis, forming the so-called *tarsal arches*. At the outer side they anastomose with the *external* or *lateral palpebrals*, which are derived from the lacrymal. The superficial temporal and transverse facial also send branches to join this anastomotic chain at the outer part of the orbit.

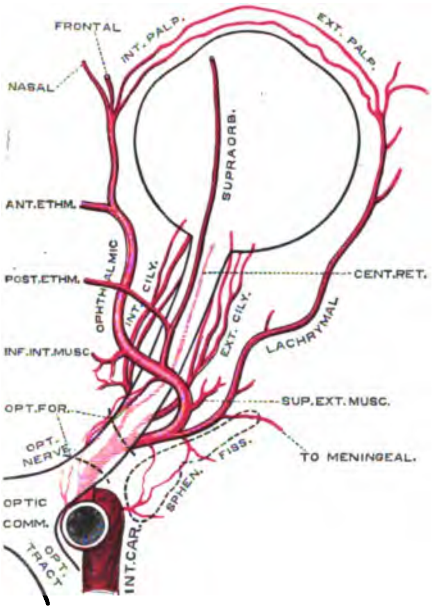

FIG. 105. — PLAN OF THE OPHTHALMIC ARTERY, SHOWING THE TYPICAL MODE OF ORIGIN OF ITS BRANCHES. (G. D. Thane, after Meyer.)

In the upper eyelid there is a secondary arterial arch formed by a branch of the superior palpebral, and running just in front of the upper or attached end of the tarsus, between the tendon of the levator palpebræ and the plain muscular sheet which passes from it to join the tarsus Sometimes there is a similar secondary arch in the lower lid. The two arches in the upper lid are joined here and there by small anastomotic arteries. Branches pass in each lid from the tarsal arches (1) forwards to supply the orbicularis muscle and the integumental structures; (2) backwards into the tarsus to supply the Meibomian glands; and (3) backwards around the upper and lower edges of the tarsus to supply the conjunctiva palpebrarum. The *veins* of the eyelids are disposed in two series or networks. The one, *post-tarsal*, receives branches from the conjunctiva and a few from the Meibomian glands; its blood passes for the most part into the ophthalmic vein. The other, or *pre-tarsal*, receives branches from the Meibomian glands and from the orbicularis and integument, below which it forms a tortuous venous plexus, with large and irregular meshes. The blood passes externally into the superficial temporal, internally into the facial vein.

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[1] Lor, Journ. del' Anat. 1898. On the structure of the Harderian gland, see Loewenthal, Anat. Anz. vii. 1892.

[2] Zietschmann Arch. f. Ophth. 1904. This paper has many details of the comparative histology of the eyelids, and a list of works on the subject. See also Contino, Arch. f. Ophth. lxvi. 1907, who deals at length with the structure and development of the parts at the edge of the eyelid.

Lymphatics.—There are two networks of lymphatic vessels in each eyelid, one in front of, the other behind the tarsus. The former receives lymph from the integumental and muscular structures of the lid, the latter from the Meibomian glands and conjunctiva. The networks are connected by vessels which pierce the tarsi, but less freely in the lower than in the upper eyelid. The efferent lymphatics find their way, mesially along the facial vein and its tributaries towards the submaxillary lymphatic glands, laterally into the pre-auricular and parotid lymphatic glands.

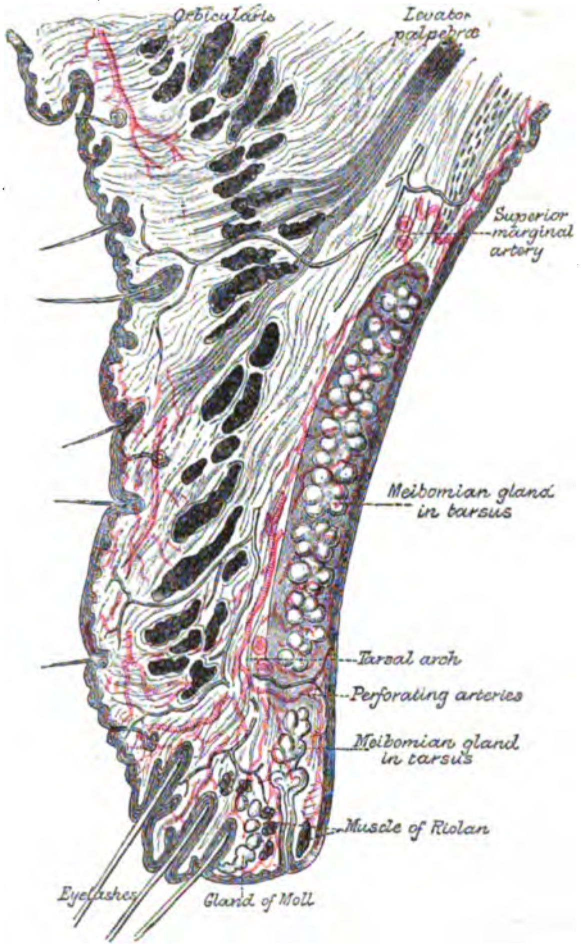

Fig. 106.—Section of the upper eyelid, with the arteries injected (Modified from Merkel.)
The course of the nervous twigs is also shown

Nerves.—The levator palpebræ is supplied by the upper branch of the third nerve, the orbicularis palpebrarum by the upper branches of the facial nerve; the plain muscular tissue of the lids, like that of the orbit generally, by branches of the sympathetic.

The sensory nerves come from branches of the fifth. The upper lid is mainly supplied by the supra-orbital, the lower lid mainly by the infra-orbital branches; but at the inner or nasal part the supra- and infra-trochlear branches of the ophthalmic division come to the surface, and assist in supplying the lids and the adjacent lacrymal apparatus, whilst laterally the auriculo-temporal sends ramifications to the skin over the external angular process, some of which may pass into the upper eyelid (fig. 107).

The principal nerves run in front of the tarsi between these and the fibres of the orbicularis. Hence their branches pass forwards to the skin, and backwards, piercing the tarsi, to the Meibomian glands and conjunctiva. Near the edge of each eyelid, between the tarsus, the orbicularis, and the ciliary bundle, is an anastomotic chain of nerve-fibres, the *marginal plexus* of Mises, from which nerves are supplied to the surrounding parts and to the hair-follicles of the eyelashes.[1]

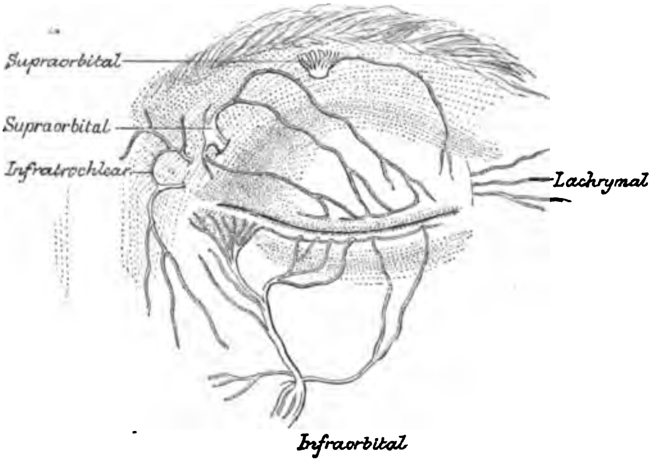

FIG. 107.—NERVES OF THE EYELIDS: LEFT EYE. (From Merkel.)

THE LACRYMAL APPARATUS.

The parts which constitute the lacrymal apparatus are the glands by which the tears are secreted; the canals which collect the fluid near the inner canthus, and the sac with the nasal duct continued from it through which the tears pass into the inferior meatus of the nose.

The **lacrymal gland** (fig. 103), an oblong flattened body, about the size of a small almond, is placed in the upper and outer part of the orbit, a little behind the anterior margin. The upper convex surface of the gland is lodged in a slight depression in the orbital plate of the frontal bone, to the periosteum of which it is united by delicate fibrous bands; the lower surface is adapted to the convexity of the eyeball, and is in contact with the upper and the outer recti muscles. The lower part of the gland is separated from the rest (fig. 113) by an expansion of the tendon of the levator palpebræ superioris, and is therefore to be regarded as a distinct gland (*glandula lacrimalis inferior* of Rosenmüller). It is closely adherent to the back of the upper eyelid, and is covered on the ocular surface merely by the conjunctiva; its lobules are small and separate, with minute ducts, some opening separately, others joining the ducts from the principal gland, which are also very small. The number from both divisions of the gland seldom exceeds twelve. After running obliquely under the mucous membrane, and separating at the same time from each other, they open in a row at the fornix conjunctivæ, by separate orifices, at its upper outer part. Here some of the ducts of the Meibomian glands may open into them (Schirmer).

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[1] On the distribution of nerves to the eyelid, see Bach in Arch. f. Ophth. xli. 1895; to the conjunctiva, Dogiel, Arch. f. mikr. Anat. xliv. 1895. On the phylogenesis of the eyelids in mammals, see H. Eggeling, Anat. Anz. xxv. 1904.

Structure.—The lacrymal gland is a compound tubulo-racemose gland, formed of short branching tubules with enlarged extremities (Marziarski), and resembling the serous salivary glands in general structure. The cells exhibit two kinds of granules—one clear and large, resembling vacuoles in appearance, the other smaller and darkly staining. During rest the clear vacuoles accumulate, but after stimulation of the secretory nerves to the gland they tend to disappear, while the dark granules are increased in amount. These changes are not at the same stage in all the alveoli of the gland.[1] Severe lacrimation, such as is produced by pilocarpine, is followed by profound changes in the cells (fig. 108). The lacrymal gland shows no crescents of Giannuzi. Some authors have described plain muscle-cells outside the epithelium both in the ducts (Zimmermann) and alveoli (Kolossow). The cells of the alveoli often contain fat-globules. As in the salivary glands, secretion-canaliculi extend from the lumen of the alveoli between the cells. The alveoli are bounded by a basement membrane formed of ramified flattened cells. No rod-like structure is noticeable in the epithelium of the ducts, which is two-layered. The intraglandular connective tissue is frequently found to be crowded with lymph-cells, especially with advancing age. The arteries of the gland are derived from the lacrymal, and the veins pass into the ophthalmic vein. The nerves come from the lacrymal branch of the ophthalmic (which receives a twig from the maxillary) and from the sympathetic. They pierce the basement membrane and ramify between the

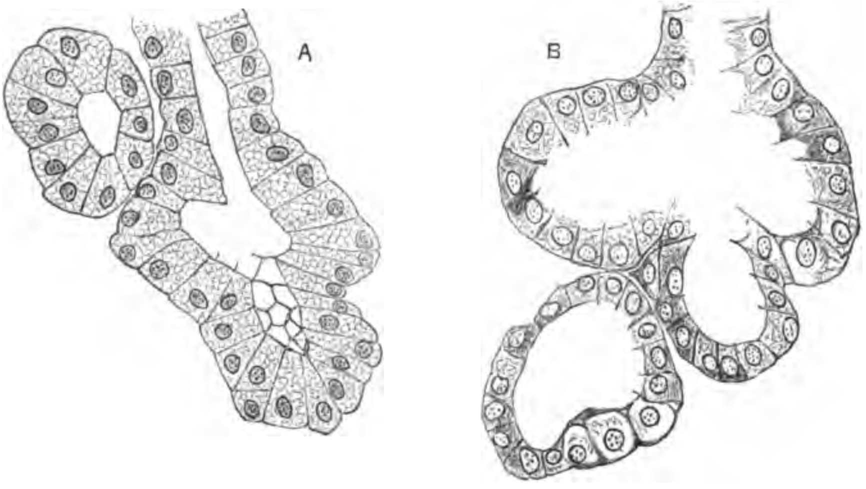

FIG. 108.—ALVEOLI OF THE LACRYMAL GLAND OF THE DOG: A, FROM A GLAND IN THE RESTING STATE; B, FROM ANOTHER GLAND WHICH HAD BEEN SECRETING FOR THREE HOURS PREVIOUSLY AS THE RESULT OF HYPODERMIC ADMINISTRATION OF PILOCARPINE. (E. A. Schäfer.)

The glands were hardened in Flemming's chromic and osmic solution. In A the cells are filled with the materials of secretion, which in the fresh preparation take the form of granules; in B, these are mostly discharged, and the cells are shrunken and relatively empty.

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[1] See on this subject, Noll in Arch. f. mikr. Anat. lviii. 1901, and Dubreuil, Thèse, Lyons, 1907.

secretory cells.[1] The cerebral fibres are probably derived from the facial and pass to the lacrymal nerve through the greater superficial petrosal to the sphenopalatine ganglion, and thence to the maxillary division of the fifth and by the nervus subcutaneus malæ through its communicating branch with the lacrymal.

Microscopic glands, having the same structure as the main lacrymal glands, are found scattered under the conjunctivæ of both eyelids, but mainly of the upper lid, and even in the tarsus and in the subcutaneous tissue of the eyelids. They are more numerous on the temporal than on the nasal side, but some are found even near the inner canthus and in the caruncle.[2]

Lacrymal canals.—These commencè, as already mentioned, by a minute aperture (*punctum*) on the margin of each lid, near the inner angle (figs. 109, 110, and 111). The upper punctum is slightly smaller and nearer the mesial plane than the lower one. The upper canal is rather the smaller; it first ascends for 2 mm. from the punctum; then makes a sudden bend, and is directed inwards and slightly downwards for 6 to 7 mm. to join the lacrymal sac. The lower canal descends from the corresponding punctum and then turns sharply inwards. Both canals are smallest at the punctum, but they are a little wider at the mouth than at the base of the papilla lacrimalis, where they only measure 0·1 mm. in diameter; they then become enlarged and present a further enlargement at the bend, where each has a marked dilatation, enlarging to 1 mm. diameter or more (fig. 110). The bend is sharper in the embryo than in later life. From this the horizontal limb passes off as a nearly cylindrical tube of about 0·6 mm. diameter, gradually narrowing to half that size. A part of the orbicularis palpebrarum (*pars lacrimalis, tensor tarsi*) runs parallel to the horizontal limbs, which are embraced by some of the muscular fibres, and when the orbicularis contracts the canals may be compressed by these fibres (Merkel).[3] The canals either unite near their end, or they open separately, but close together, into a diverticulum of the nasal sac which is known as the *sinus of Maier*. Their mucous membrane is lined by stratified epithelium set on a corium rich in elastic fibres.

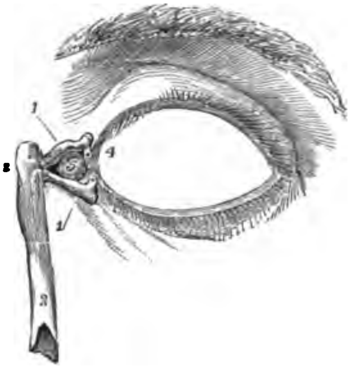

FIG. 109.—FRONT OF THE LEFT EYELIDS WITH THE LACRYMAL CANALS AND NASAL DUCT EXPOSED.

1, 1, upper and lower lacrymal canals, showing towards the eyelids the narrow bent portions and the puncta lacrimalia; 2, lacrymal sac; 3, the lower part of the nasal duct; 4, plica semilunaris; 5, caruncula lacrimalis.

The **lacrymal sac** and **nasal duct** constitute together the passage by which the tears are conveyed from the lacrymal canals to the cavity of the nose. The *lacrymal sac* (fig. 109, 2; fig. 110 *l.s.*), the slightly dilated upper or orbital portion of the passage, is situated at the side of the nose, near the inner canthus of the eye, and lies imbedded in a deep groove in the lacrymal and maxillary bones, from which it is separated by a thin layer of the orbital periosteum. When distended with tears it forms a distinct swelling here at the side of the nose. It is about 15 mm. long, and about 5 or 6 mm. wide, and is sometimes narrower below where it passes into the nasal duct. Its upper end is closed and rounded, forming a *cul-de-sac*; the lower end gradually narrows into the nasal duct. On the outer side, and a little in front, it receives the lacrymal canals; and here it is placed behind the internal tarsal ligament, and some of the inner fibres of the orbicular muscle of the lids; while on its orbital surface is the tensor tarsi muscle. The *nasal duct*, very variable in length (12 to 24 mm.), and 3 or 4 mm. wide, grooving the upper maxilla, descends to the fore-part of the lower meatus of the nose, the osseous canal being completed by the lacrymal and lower turbinate bones. Both sac and duct are composed of fibrous and elastic tissues, adhering closely to the bones above mentioned, and strengthened in the case of the lacrymal sac by a fibrous process sent from the internal tarsal ligament, which crosses it a little above its middle. The inner surface is lined by a mucous membrane, which is continuous through the canaliculi with the conjunctiva, and through the nasal duct with the mucous membrane of the nose.

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[1] A. Dogiel, Arch. f. mikr. Anat. xliv. 1895.

[2] For the literature of the lacrymal apparatus, see Schirmer, 'Mikroskopische Anatomie der Thränenorgane' in Graefe-Saemisch, Handb. d. gesamten Augenheilkunde (2nd ed.), 1904.

[3] According to Halben (Arch. f. Ophth. 1904), the contraction of these fibres would tend to produce dilatation of the canaliculi. The literature of the structure of the lacrymal passages will be found in this paper.

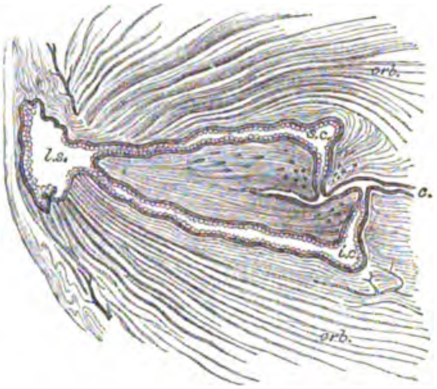

FIG. 110.—SECTION OF THE EYELIDS, PASSING ALONG THE LACRYMAL CANALS. Magnified. (Gerlach.)

c., inner canthus of eye; *s.c.*, *i.c.*, superior and inferior canals respectively; *l.s.*, lacrymal sac; *orb.*, fibres of orbicularis muscle.

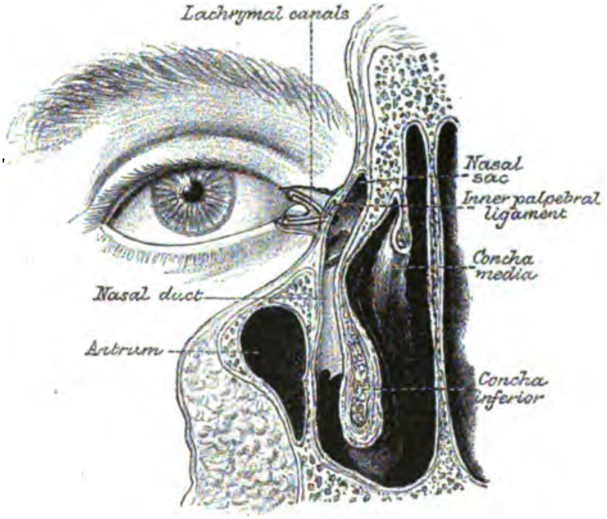

FIG. 111.—SECTION SHOWING THE COURSE AND RELATIONS OF THE NASAL SAC AND DUCT. (Slightly modified from Merkel.)

At the opening into the nose the lining membrane is often arranged so as to form an imperfect valve (Hasner). Other valvular folds have been often noticed and described, but they appear to be less constant. The nasal duct is rather narrower in the middle than at either end; its direction is not quite vertical, but inclined slightly backwards. Its direction is indicated by a line joining the mesial canthus of the eyelids with the anterior edge of the first molar of the upper jaw (Testut). The lower orifice of the nasal duct is very variable in position, but is usually from 30 to 35 mm. behind the posterior margin of the anterior nasal opening (Arlt). It may open by a simple round orifice close under the inferior turbinate, or by an oblique or slit-like orifice or groove in the mucous membrane somewhat lower. In rare cases two lower openings have been described. This condition is always present in some animals (*e.g.* dog).

The nasal sac and duct are lined by a columnar epithelium, which may be ciliated here and there, but does not appear to be covered everywhere with cilia as is the case on the adjacent mucous membrane of the nose. The lower part of the nasal duct has numerous glands similar to those in the nasal meatus into which it opens. The arteries come from the nasal and inferior palpebral. The veins are very large and numerous on the nasal duct (as in the adjacent nasal mucous membrane). The nerves are derived from the infratrochlear branch of the nasal division of the ophthalmic.

THE GLOBE OF THE EYE.

The globe or ball of the eye is supported by a quantity of fat and loose connective tissue in the fore-part of the orbital cavity, somewhat nearer its lateral and inferior walls than its mesial and superior. As a rule the anterior part of the eyeball does not protrude beyond a vertical line uniting the anterior margins of the roof and floor of the orbit, but fully one-half of the eyeball is in front of the outer wall. The recti and obliqui muscles closely surround the greater part of the eyeball: the lids, with the plica semilunaris and

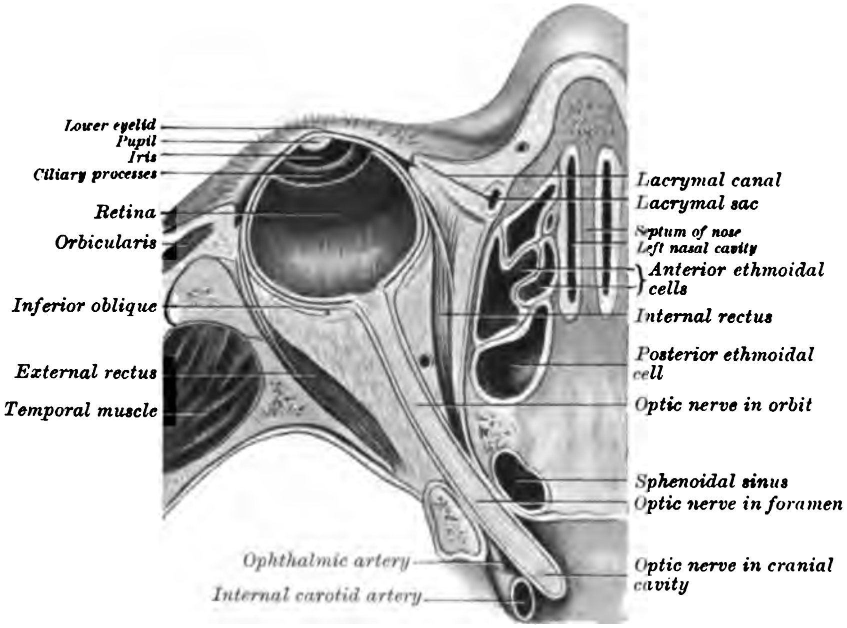
Lower eyelid
Pupil
Iris
Ciliary processes
Retina
Orbicularis
Inferior oblique
External rectus
Temporal muscle
Lacrymal canal
Lacrymal sac
Septum of nose
Left nasal cavity
Anterior ethmoidal cells
Internal rectus
Posterior ethmoidal cell
Optic nerve in orbit
Sphenoidal sinus
Optic nerve in foramen
Optic nerve in cranial cavity
Ophthalmic artery
Internal carotid artery

FIG. 112.—HORIZONTAL SECTION OF LEFT ORBITAL CAVITY, VIEWED FROM ABOVE; VITREOUS AND LENS REMOVED FROM EYEBALL. Natural size. (J. Symington.)

caruncle, are in contact with its covering of conjunctiva in front; and behind, it receives the thick stem of the optic nerve.

The eyeball is composed of segments of two spheres, of which the anterior is the smaller; the segment of the larger posterior opaque sphere corresponds with the limit of the sclerotic coat, that of the smaller sphere with the cornea.[1]

The eyeball measures nearly an inch across from side to side, but, according to most authorities, slightly more from before back, and slightly less from above down. In the myopic it is longer and in the hypermetropic shorter from before back than in the normal eye. The globe weighs nearly 7 grammes, and has a volume of about 6·5 cubic centimetres. According to Baker, it weighs about 3·8 grammes at birth; its antero-posterior diameter in the new-born child is stated by Jaeger to be 17·53 mm. The proportion to body-weight for the two eyes is given as 1 : 4832 for the adult and 1 : 491 for the child at birth.

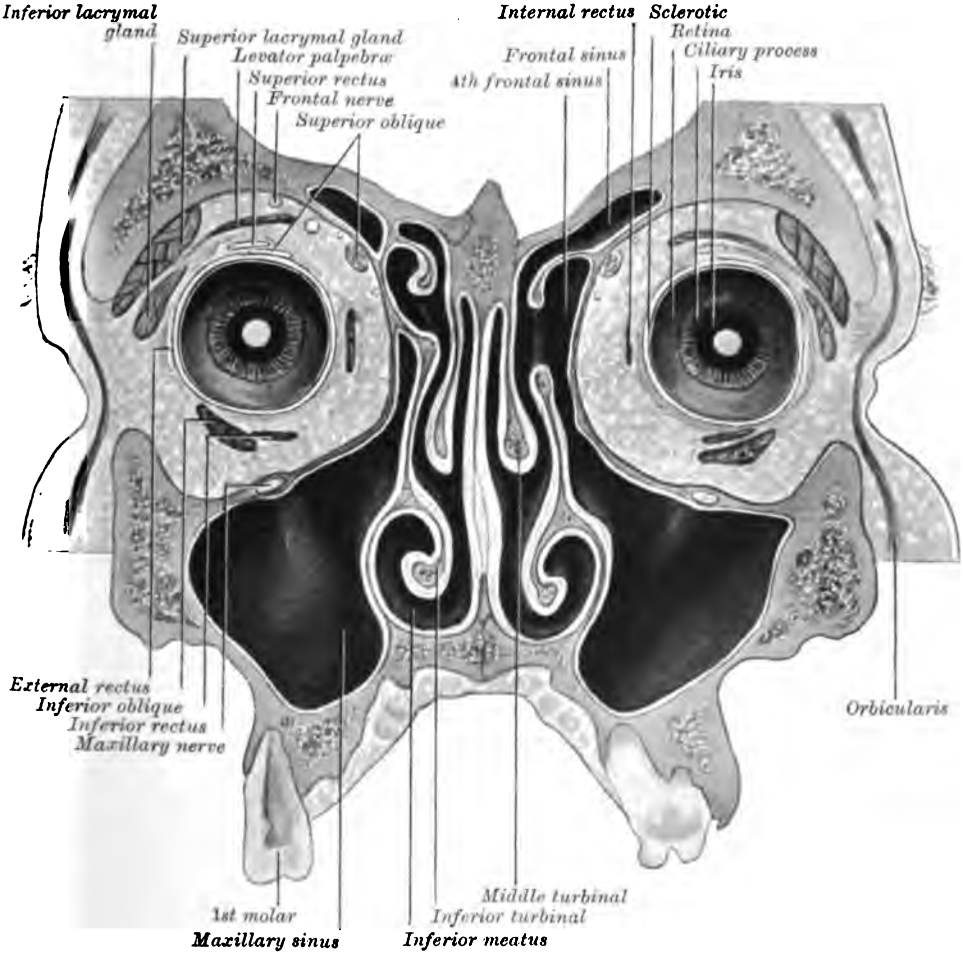
Inferior lacrymal gland
Superior lacrymal gland
Levator palpebræ
Superior rectus
Frontal nerve
Superior oblique
Internal rectus
Frontal sinus
4th frontal sinus
Sclerotic
Retina
Ciliary process
Iris
External rectus
Inferior oblique
Inferior rectus
Maxillary nerve
Orbicularis
1st molar
Maxillary sinus
Middle turbinal
Inferior turbinal
Inferior meatus

FIG. 118.—CORONAL SECTION OF THE HEAD OF AN ADULT MALE, 2¾ INCHES IN FRONT OF THE EXTERNAL AUDITORY MEATUS, VIEWED FROM BEHIND. Natural size. (J. Symington.)

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[1] According to Koster-Gzn, the larger sphere is somewhat flattened behind. Arch. f. Ophth. 1901.

Except when directed towards near objects, the axes of the eyes are nearly parallel; the optic nerves, on the contrary, diverge considerably. Each nerve enters the corresponding eye to the inner or nasal side of the axis of the eyeball (fig. 112), and a little below the horizontal plane bisecting the globe.

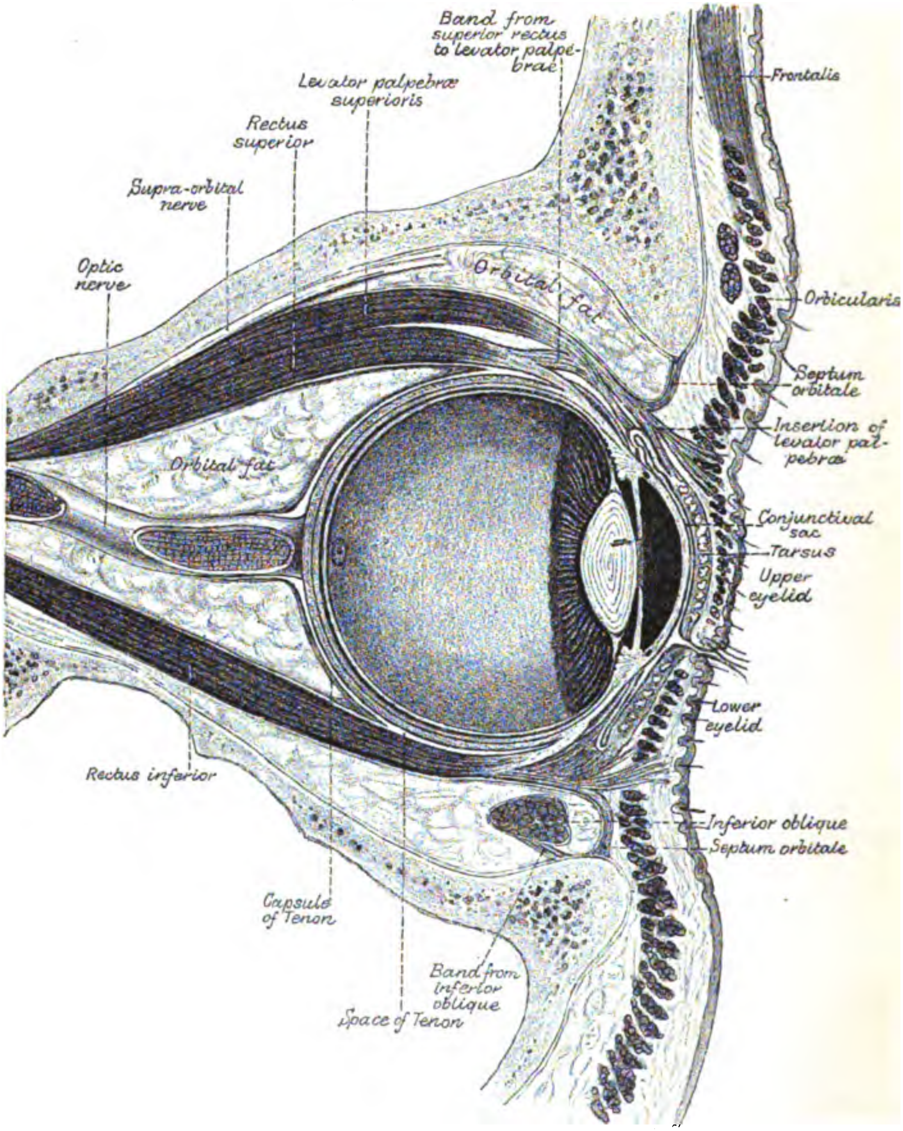
Band from superior rectus to levator palpebræ
Levator palpebræ superioris
Rectus superior
Supra-orbital nerve
Optic nerve
Frontalis
Orbital fat
Orbicularis
Septum orbitale
Insertion of levator palpebræ
Orbital fat
Conjunctival sac
Tarsus
Upper eyelid
Lower eyelid
Rectus inferior
Inferior oblique
Septum orbitale
Capsule of Tenon
Band from inferior oblique
Space of Tenon

FIG. 114.—SAGITTAL SECTION THROUGH THE MIDDLE OF THE GLOBE OF THE EYE WITHIN THE ORBIT. (From a figure by Merkel, enlarged and modified.)

The eyeball consists of three concentric coats, and of certain fluid and solid parts enclosed by them. The coats are (1) an external fibrous covering, forming the *sclerotic* or *sclera* (*tunica sclera*) and *cornea*; (2) a middle vascular, pigmented, and in part also muscular membrane, the *choroid* and *iris* (*tunica uvea*); and (3) an internal nervous and epithelial stratum, the *retina*. The enclosed refracting media, three in number, are the *aqueous humour*, the *vitreous body*, and the *lens*.

Around the posterior two-thirds of the eyeball there is a tunic of fascia, *tunica vaginalis oculi*, or *capsule of Tenon*, which is perforated by the tendons of the recti and obliqui muscles, along which it sends sheaths which blend with the perimysium of the muscles (fig. 114). It is connected with the sclerotic by delicate connective tissue (*adventitia oculi*, Lockwood), but posteriorly, at the entrance of the ciliary vessels and nerves, it blends with the sclerotic. Anteriorly the capsule of Tenon is continued into the conjunctiva. This capsule is lined by flattened endothelial cells, and encloses a lymph-space, which separates the eyeball from the orbital fat. It is strengthened, just behind the places where the recti muscles perforate it, by bands of fibrous tissue, and it is attached on either side to the malar and lacrymal bones by elastic ligamentous structures, which also receive fibrous slips from the internal and external recti. These structures serve as check-ligaments to these muscles. According to Sappey, they contain plain muscular fibres. Fibrous slips also pass from the sheaths of the superior and inferior rectus, and are attached to the conjunctiva palpebrarum and to the connective tissue of the eyelid (fig. 114). Below and in front of the anterior end of the inferior rectus the capsule is strengthened by a band of fibrous tissue, which is stretched like a sling from one side of the orbit to the other, and is inserted at its ends into the lacrymal and malar bones. This band—the *ligamentum suspensorium oculi* of Lockwood—serves to aid in maintaining the eye in position; it is joined anteriorly with the tarsus of the lower lid. Lastly, another band passes from the anterior border of the sheath of the inferior oblique muscle forwards, downwards, and outwards, to be attached to the lateral part of the lower border of the orbit (fig. 114).[1]

H. Müller[2] described a layer of unstriped muscle bridging over the sphenomaxillary fissure, corresponding to a more largely developed layer found in the extensive aponeurotic part of the orbital wall of various mammalia. These involuntary muscles receive their nerves through the cervical sympathetic. The sphenomaxillary muscle, when contracted, may cause the globe of the eye to project more from the orbit, but can only do so to a very limited extent in man.

THE SCLEROTIC COAT.

The **sclerotic coat** or **sclera,** the tunic of the eye on which the maintenance of the form of the organ chiefly depends, is a strong, opaque, fibrous structure, which during life is maintained at a certain degree of tension by the pressure of the fluid contents of the globe (*intra-ocular pressure* = about 26 mm. Hg.). The sclera extends over the greater part of the eyeball (fig. 115), joining in front with the cornea. The outer surface is white and smooth, except where the tendons of the recti and obliqui muscles are inserted into it. In the child the eyeball has a bluish-white colour, from the fact that the dark pigment of the choroid shows through the sclerotic coat (which is thinner in the child). The inner surface is brown and rough, from the presence of a delicate pigmented connective tissue (*lamina fusca*), which is united by fine threads with the choroid coat. These filaments traverse a lymph-space through which branches of the ciliary vessels and nerves pass obliquely. The sclerotic is thickest at the back part of the eye, at the entrance of the optic nerve, where it is nearly 1 mm. thick, and thinnest (0·4 mm.) at about 6 mm. from the cornea: near the junction with the latter, it is again somewhat thickened (0·6 mm.), in association with the attachment of the tendons of the recti muscles.

The attachments of these tendons spread out somewhat at the sclerotic, but do not unite with one another, nor are they at the same distance from the edge of the cornea. The following, according to Fuchs, are the distances of the several attachments—viz. internal rectus, 5·5 mm.; inferior, 6·5 mm.; external, 6·9 mm.; and superior rectus, 7·7 mm. The attachments of the oblique muscles are both in the posterior hemisphere: that of the superior oblique is above the horizontal plane bisecting the globe and crosses the vertical meridian; that of the inferior is immediately below the horizontal plane (fig. 116). The inferior oblique has no tendon, but is directly attached to the sclera.

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[1] For further details, see Lockwood, Journal of Anatomy and Physiology, 1885.

[2] Würzburg Sitzungsb. 1858. See also W. Turner, Nat. Hist. Rev. 1862.

The optic nerve pierces the sclera about 2·5 to 3 mm. internal to the posterior pole of the eyeball, and about 1 mm. below a horizontal plane passing through the poles; the opening is somewhat smaller at the inner than at the outer surface of the coat. The outer fibrous sheath of the nerve blends with the sclerotic at the margin of the aperture: in consequence of this arrangement, when the nerve is cut off close to the eyeball the funiculi seem to enter by a group of pores; and to the part of the sclerotic thus perforated the name of *lamina cribrosa* is given. Around this opening are smaller apertures for the posterior ciliary arteries and the ciliary nerves. Nearer the equator of the globe the sclerotic is pierced by four apertures which transmit the veins (venæ vorticosæ) of the choroid coat (see fig. 140).

Fig. 115 has been drawn approximately to scale (× 5), the following being taken as the average measurements of the parts of the adult eye in millimetres[1]:

Transverse diameter of the eyeball	24·5
Vertical diameter	23·5
Antero-posterior diameter	24·0
Greatest thickness of the sclerotic, choroid, and retina together	1·4
Thickness of the sclerotic posteriorly	0·8
Thickness of the sclerotic at the equator	0·4
Thickness of the cornea in the centre	0·8
Distance from the middle of the anterior surface of the cornea to the front of the lens	3·6
The same in the fully accommodated eye	3·2
Antero-posterior diameter of the lens	4·0
Transverse diameter of the lens	9·1
Greatest thickness of the ciliary body	1·1
Thickness of the iris	0·4
Length of the radius of curvature of the anterior surface of the cornea	7·8
Radius of the posterior surface of the sclerotic	12·5
Radius of curvature of the anterior surface of the lens	10·0
The same in the fully accommodated eye	6·0
Radius of the posterior surface	6·0
The same in the fully accommodated eye	5·0
Distance of the middle of the posterior surface of the lens from the retina	15·0
Distance between the centre of the spot of entrance of the optic nerve and the middle of the fovea centralis retinæ	3·5

Structure of the sclera.—The sclerotic coat is formed of bundles of connective-tissue fibres (figs. 117, 118), and yields gelatine on boiling. Its white fibres are combined with fine elastic elements, and amongst them lie numerous connective-tissue corpuscles lodged in cell-spaces, but not by any means so regularly arranged as in the cornea. Some of the cells are pigmented. The bundles are disposed in layers both longitudinally and transversely, the longitudinal arrangement being most marked behind and at the surfaces, the transverse or circular near the corneal margin. The layers communicate at the posterior part of the sclerotic its vessels are continuous with those of the dural sheath of the optic nerve. Around this nerve the scleral branches of the posterior ciliary arteries form an arterial circle (*circulus Zinnii*), which give branches to the optic nerves and choroid as well as to the sclerotic. The vessels of the conjunctival membrane, which are derived from the palpebral and lacrymal arteries, are readily distinguishable from those of the subjacent sclerotic by their more tortuous course, and by the fact that they shift upon the globe when the conjunctiva is pulled upon. Near the edge of the cornea they communicate with the episcleral vessels derived from the anterior ciliary. Veins corresponding with the arteries, but smaller and more numerous, run in and beneath the conjunctiva; they commence in a close *circumcorneal network* of episcleral vessels, which forms a band about 5 mm. wide around the corneal margin, receiving blood from the fine looped capillaries which extend to that margin (fig. 120), and also from those of the conjunctiva, and there is a well-marked scleral plexus of veins behind the junction of the cornea and sclerotic and penetrating the substance of the sclerotic. The deepest part of this plexus is formed by the canal of Schlemm (see p. 201). The veins convey their blood to

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[1] Sappey gives the diameters of the eyeball as follows: transverse, 23·6 mm.; vertical, 23·2; antero-posterior, 24·2; these numbers representing the average of the eyes of twenty-six individuals of various ages (from 18 to 81) and both sexes. All the measurements were on an average slightly smaller in the female than in the male sex. A concise account of the results arrived at by different authorities is given in the article on the Anatomy of the Eyeball by F. Baker in Norris and Oliver's System of Diseases of the Eye, 1897.

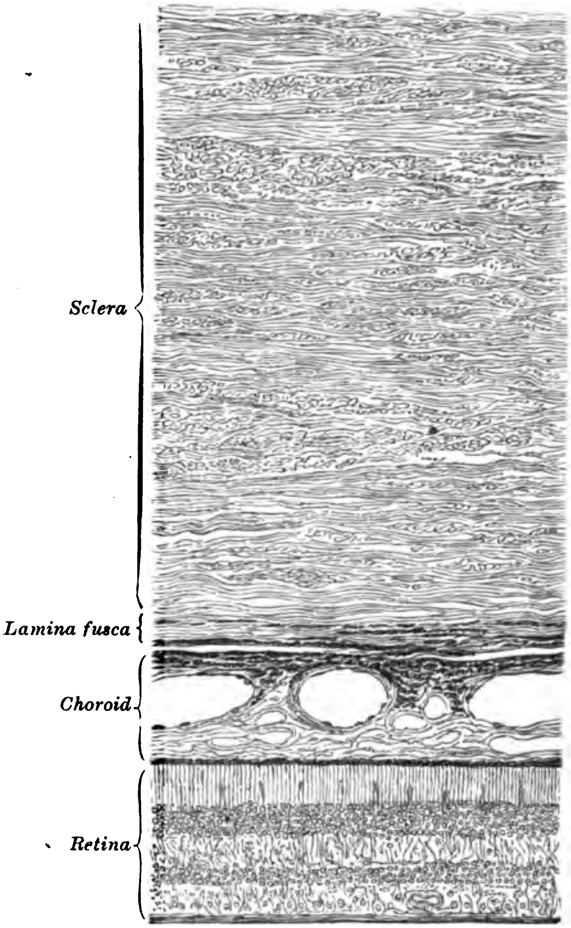

FIG. 117.—SECTION THROUGH THE COATS OF THE EYEBALL. (Merkel and Kallius.)

the anterior ciliary veins and the vorticose veins of the choroid. There are no lymphatics in the substance of the sclera.

The sclerotic receives fibres from the ciliary nerves, but it is not certainly known how they terminate. According to Königstein,[1] they end in arborisations between the fibril-bundles, and are characterised by the tortuous course of their fibrillæ.

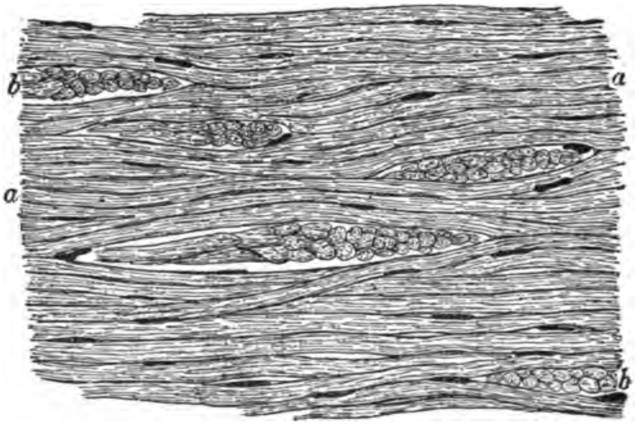

Fig. 118.—Section of sclera showing the component fibrous tissue (*a*) arranged as interlacing lamellæ: in the clefts between the bundles lie the scleral cells; *b*, obliquely cut bundles of circularly disposed fibres. Magnified 480 diameters. (Piersol.)

Hannover described the sclerotic as being traversed in its thickness, opposite the fovea centralis of the retina, by a strand of fibrous tissue, which unites the laminæ as it passes through them (*funiculus scleræ*). According to Schwalbe, the strand thus described is merely connective tissue which accompanies the most lateral group of posterior ciliary arteries as they pierce the sclerotic.

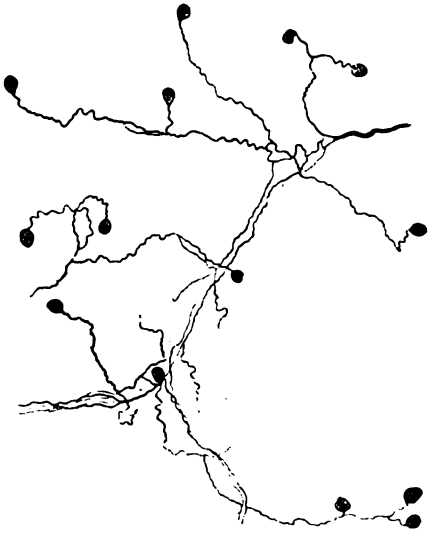

Fig. 119.—Termination in end-bulbs of the nerves of the conjunctiva. (Longworth.)

THE CORNEA.

The **cornea**, the transparent fore-part of the external coat, admits light into the interior of the eyeball. It is nearly circular in shape, but is slightly wider in the transverse than in the vertical direction (about 12 mm. and 11 mm. diameter respectively); its arc extends to about one-sixth of the circumference of the whole globe. The cornea has a curvature of a smaller radius than the sclerotic; the degree of its curve varies, however, in different persons, and at different periods of life in the same person, being more prominent in youth than in advanced age. It is also normally a trifle more curved in the vertical than in the horizontal plane. Its thickness is nearly the same throughout, being slightly less than a millimetre, but it is thinner near the centre than at the periphery. The posterior or concave surface exceeds slightly in extent the anterior or convex, in consequence of the latter being encroached on by the superficial part of the sclerotic; the cornea being overlapped by the sclerotic like a watch-glass by the edge of the groove into which it is received (see fig. 115); the tissues of the two are, however, in complete continuity.

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[1] Arch. f. Ophth. 1881.

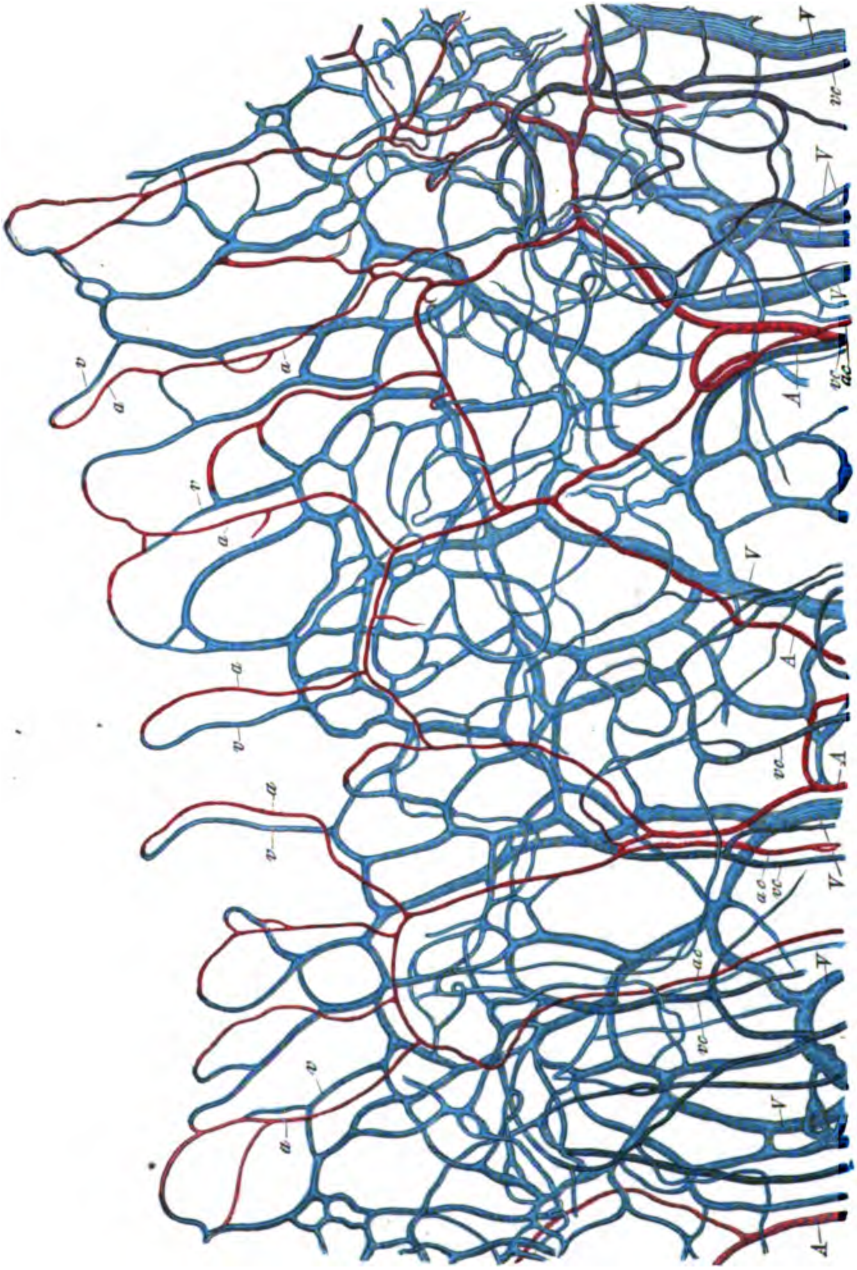

FIG. 120.—LOOPED VESSELS IN THE CONJUNCTIVA AT THE BORDER OF THE CORNEA, SHOWING THEIR CONTINUITY WITH THE EPISCLERAL VENOUS NETWORK: MAN. (Leber.)

A, *A*, Episcleral branches of anterior ciliary arteries; *V*, *V*, the same of the corresponding veins, connected together into an episcleral venous network; *a* arterial, *v* venous parts of the looped capillaries; *ac*, *vc*, branches given off from the episcleral arteries and veins to the conjunctiva.

Around the junction a slight groove is apparent in the surface of the globe (*sulcus scleræ*). This is produced less by the projection of the cornea than by the dipping in of the sclera. If the latter were continued around the front of the eye with the same radius of curvature as it has around the back, it would project beyond the cornea. The tissue of the cornea readily imbibes aqueous humour and becomes opaque after death.

The curvature of the cornea is not the same throughout. According to Aubert, it is more curved in the central part,[1] which forms the so-called 'optic zone,' about 4 mm. in diameter (*i.e.* about one-third of the whole cornea). The peripheral or 'border zone' is more flattened than the optic zone, but its curvature is not quite the same in all meridians.

Helmholtz gave the thickness of the cornea in the middle as 1·37 mm., and at the edge as 1·55 mm., but Blix and others have found these numbers too high.

The refractive index of the cornea is 1·3763 (water = 1·331), which for a radius of curvature of 7·8 gives a refractive power of about 48 diopters.[2]

Structure of the cornea.[3]—The cornea may be described as consisting of (1) a stratified epithelium in front (fig. 121, 1) continuous with the epithelium of the conjunctiva; this rests upon an anterior homogeneous lamella (2), belonging to the next part; a substantia propria (3), continuous with the sclerotic, composed of modified connective tissue; a posterior homogeneous lamella (4); which is itself covered with a simple layer of endothelium cells (5).

Epithelium of the cornea.—The epithelium covering the front of the cornea is of the stratified kind, the cells being in man five deep (fig. 122), except near the edge of the cornea, where more layers are added. The lowermost cells are columnar, with a flattened base, where they rest on the substantia propria, and a rounded apex, upon which a cell of the next layer fits. To the base of each columnar cell is attached a broad, flattened, strongly refracting process, which projects under one of the neighbouring cells (not shown in the figure). Above these columnar cells are two or three layers of polygonal cells, some of the deeper of which (the *fingered cells* of Cleland) have projections from their under surface which fit between the cells below. These polygonal cells have well-marked denticulations, which join one another across the intercellular spaces which separate the cells. Quite superficially is a stratum of flattened scaly epithelium-cells, which retain their nuclei and are not converted into horny substance, as are those of the epidermis.

The **proper substance** of the cornea is composed, as before said, of a modified form of connective tissue, all the constituents of which have very nearly the same index of refraction, so that in the perfectly fresh condition it is difficult, even with the best lenses, to make out any indications of structure. After death, however, and with the assistance of reagents, the cornea may be ascertained to consist of alternating lamellæ of fibrous tissue (about sixty in number, according to Bowman), the planes of which are parallel to the surfaces of the cornea. The fibres composing the lamellæ are nearly straight and have a definite direction in each layer; they cross one another at various angles in the alternate layers, often nearly at right-angles. It must, however, be understood that the layers are not individually distinct, but give off frequent offsets to those above and below, so that they cannot readily be stripped away for any distance. The fibrils are collected into bundles, which, as well as the laminæ they form, are, as in the connective tissue elsewhere, separated from each other by ground-substance. The latter is in greater abundance between the fibrous strata than elsewhere, and in these parts the cell-spaces of the tissue are found. These cell-spaces, which are readily demonstrated by staining the tissue with nitrate of silver (fig. 124), are flattened conformably with the lamellæ, are of an irregularly stellate figure, and freely communicate by their offsets both with others on the same plane and with those above and below. The greater

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[1] The radius of curvature of this part is less in women and children than in men (Donders) and increases with age (Steiger). On the size of the cornea in relation to age and sex, see Priestley-Smith, Brit. Med. Journ. 1889.

[2] For the dioptrics not only of the cornea, but also of the other refractive structures of the eye, the article by Hess in Graefe-Saemisch, Handbuch der gesammten Augenheilkunde (2nd ed.), may be consulted.

[3] The fullest recent account of the structure of the cornea is that given by H. Virchow, in Graefe-Saemisch, Handb. d. ges. Augenheilk. (2nd ed.), where also will be found the chief literature of the subject down to 1904.

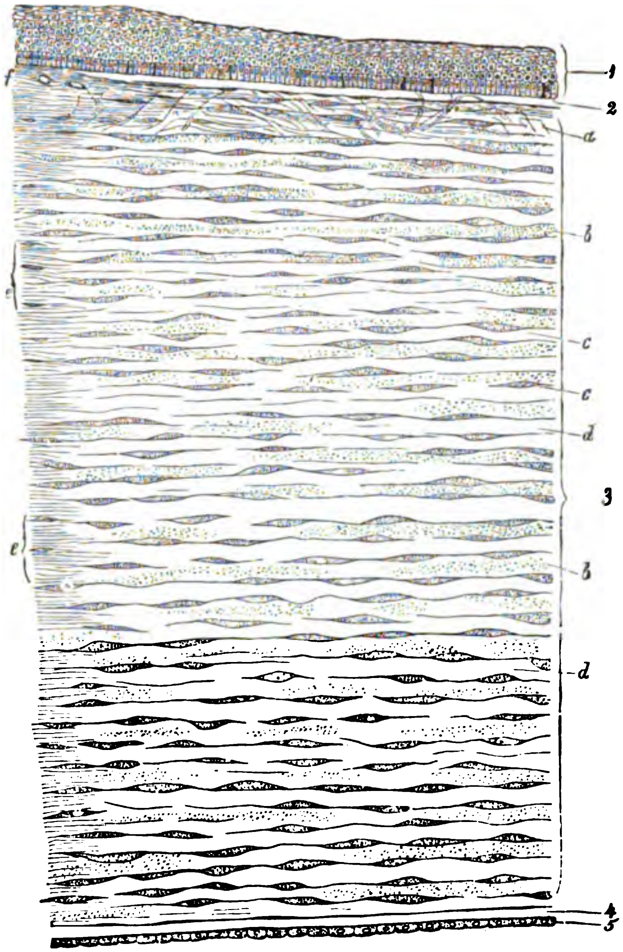

Fig. 121.—Vertical section of human cornea from near the margin. Magnified. (Waldeyer.)

1, epithelium; 2, anterior homogeneous lamina; 3, substantia propria corneæ; 4, posterior homogeneous (elastic) lamina; 5, endothelium of the anterior chamber; *a*, oblique fibres in the anterior layer of the substantia propria; *b*, lamellæ the fibres of which are cut across, producing a dotted appearance; *c*, corneal corpuscles appearing fusiform in section; *d*, lamellæ the fibres of which are cut longitudinally; *e*, transition to the sclerotic, with more distinct fibrillation, and surmounted by a thicker epithelium; *f*, small blood-vessels cut across near the margin of the cornea.

regularity of arrangement which characterises them, as compared with the cell-spaces of connective tissue elsewhere, is dependent on the regularly laminated structure of the cornea. In addition to the bundles of white fibres, the cornea is stated by Tartuferi[1] to contain numerous elastic fibres forming perifascicular networks and occurring in all layers and parts. But other observers have for the most part failed to recognise so large a number of elastic fibres, and find the latter only near the conjunctival border.[2]

The cells of the tissue—*corneal corpuscles*—lie within the cell-spaces, corresponding generally with them in form, but without entirely filling them, the room left serving for the passage of lymph and lymph-corpuscles, which are occasionally found in the spaces. The protoplasm of the corpuscles is clear, except in the neighbourhood of the nucleus, where it is more granular; the cells send branching processes along the anastomosing canals of the cell-spaces, which join with those of neighbouring corpuscles. In sections across the thickness the corpuscles appear fusiform (fig. 121, *c*), but tangential sections show them to be flattened conformably with the surface. As Ballowitz[3] has shown, the corneal cells all have centrosomes, mostly double. The nuclei of the cells are very various in shape and undergo changes in form in the course of growth, and again with the supervention of age. The interconnexion of the cells is fairly close, but they can be isolated without difficulty after maceration in hydrochloric acid (fig. 125).

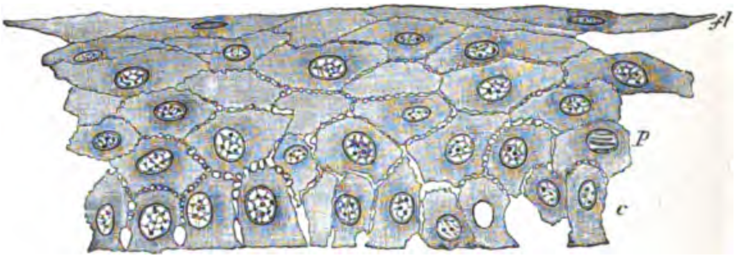

FIG. 122.—VERTICAL SECTION THROUGH THE EPITHELIUM OF THE HUMAN CORNEA. Highly magnified. (E. A. Schäfer.)

c, deepest columnar cells; *p*, polygonal cells, immediately above them; *fl*, flattened cells of the surface.

The section is slightly broken on the right of the figure. The intercellular channels bridged across by processes extending from one cell to another are distinctly seen.

The cell-spaces can be filled with fluid injection by inserting the nozzle of a fine syringe into the tissue, and employing a very low pressure; in this way a network of anastomosing stellate figures is obtained (Recklinghausen's canals). If, however, the injection-fluid is dense, or too forcibly injected, it becomes extravasated in the interstices of the fibril-bundles, the direction of which it takes; and the appearance is produced of minute swollen tubular passages running at right-angles to one another in the different layers (Bowman's corneal tubes). This appearance may still more readily be obtained if air is injected into the tissue instead of mercury (the fluid used by Bowman), and it is seen that the injection always stops at the margin of the cornea, where the tissue becomes closer as it passes into the sclerotic, whereas Recklinghausen's canals are continued into the cell-spaces of the sclerotic.

Frequently in advancing age there occurs a granular deposit at the margin of the cornea, forming a whitish opaque ring about 1 mm. from the corneo-sclerotic junction. This ring is known as the *arcus senilis.* It is not due, as was formerly supposed, to deposition of fat in the cells, but to a kind of granular degeneration of the fibres of the tissue (Fuchs).

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[1] Arch. f. Ophth. 1903.

[2] Cf. Stutzer, Arch. f. Ophth. xlv. 1898; Carlier, Journ. Anat. and Physiol. xl.; and Lieto-Vollaro, Ann. ottalmol. xxxvi. 1907.

[3] Arch. f. Ophth. xlix. 1899.

Anterior homogeneous lamella.—The part of the cornea immediately beneath the anterior epithelium, for a thickness of 0·01 mm. to 0·02 mm., appears entirely free from fibres and corpuscles, constituting the *anterior homogeneous lamina* of Bowman (fig. 123). According to Rollett, by the use of appropriate reagents a fibrillar structure can be demonstrated within it, and near the margin bundles of fibres may be seen passing obliquely from its deeper surface into the proper substance. But it differs in chemical nature from the proper substance, being unaffected by dilute acids and reacting differently to certain stains. It is thickest in the middle, thinning off gradually towards the edges of the cornea. In some animals a layer of flattened cells may be detected on its anterior surface, under the epithelium. The lamella is better marked in man than in most animals.

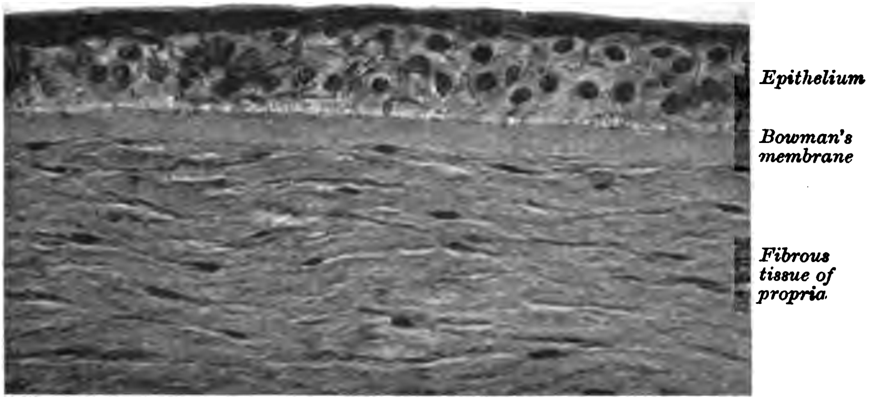

FIG. 123.—SECTION OF HUMAN CORNEA, SHOWING THE EPITHELIUM, THE ANTERIOR HOMOGENEOUS LAMELLA, AND THE MOST SUPERFICIAL LAYER OF THE PROPRIA. (E. A. Schäfer.)

Posterior homogeneous lamella, or **membrane of Descemet** (*posterior elastic lamina,* Bowman) (fig. 121, 4). This is not very closely united with the fibrous part of the cornea. It is transparent and glassy in appearance, somewhat tough, and very elastic; when shreds are removed from it they tend to curl up with the attached surface innermost. It is not readily affected by acids, by boiling in water, or by maceration in alkalies; under some conditions it can be split up into very fine lamellæ. It differs from elastic tissue in being stained brown with osmic acid and purple with hæmatoxylin; it is also less resistant to the digestive action of trypsin. In thickness it varies from 0·006 mm. to 0·012 mm., being thinnest in the middle and thickening towards the margin. Here also there are apt to develop, in adult age, low papilliform projections on the inner surface of the membrane; with old age these become more marked and the whole membrane becomes thicker, and may measure as much as

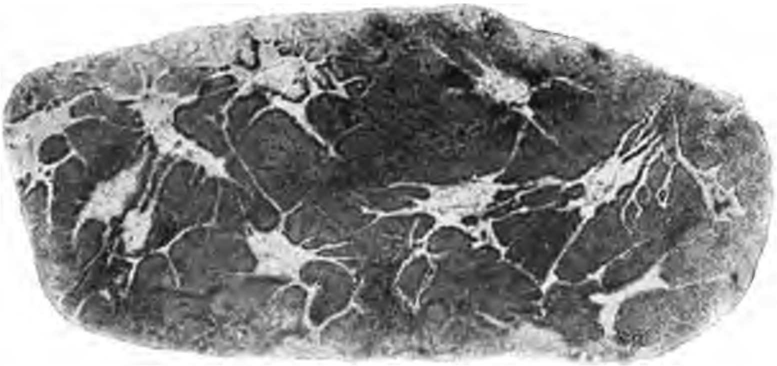

FIG. 124.—CORNEA OF RABBIT STAINED WITH NITRATE OF SILVER. Magnified 800 diameters. Photographed from a preparation by H. Pringle.

The ground-substance is darkly stained of a brown colour, the cell-spaces being left white. The irregularity of the spaces and their intercommunication by processes is well shown. This figure is to be compared with the next one, in which the cells themselves are stained.

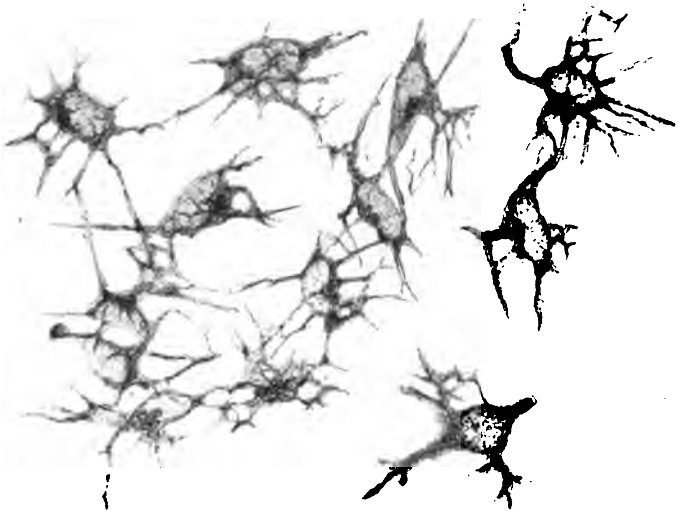

FIG. 125.—CORNEAL CORPUSCLES OF RABBIT STAINED WITH GOLD CHLORIDE AND PARTIALLY ISOLATED WITH HYDROCHLORIC ACID. Magnified 300 diameters. (E. A. Schäfer.)

The cells are united by their processes, and it is only by rupture of the connexion that they become entirely separated from one another. They therefore form a complete protoplasmic network throughout the corneal substance, and, as the result of silver staining shows (fig. 124), the spaces in which the cells lie are also in intercommunication.

0·02 mm. It is lined next to the anterior chamber with a pavement endothelium (fig. 121, 5), which resembles that on serous membranes, consisting of a single layer of flattened polygonal cells with circular, elliptic, or horseshoe-shaped nuclei (fig. 127). The cells also exhibit with appropriate staining a reticular body lying near the nucleus, apparently of the nature of a paranucleus.[1] The cells are not everywhere in close contact, gaps occurring here and there which appear as enlargements of the intercellular substance. Nevertheless the epithelium of Descemet's membrane, while intact, entirely prevents absorption of the aqueous humour into the corneal substance. In birds the cells are traversed by bundles of fine fibrils which pass from cell to cell across the intercellular spaces (fig. 126). The fibrils are probably formed by threads of protoplasm; they undergo rapid alteration, and very soon disappear after death or removal of the globe.[2]

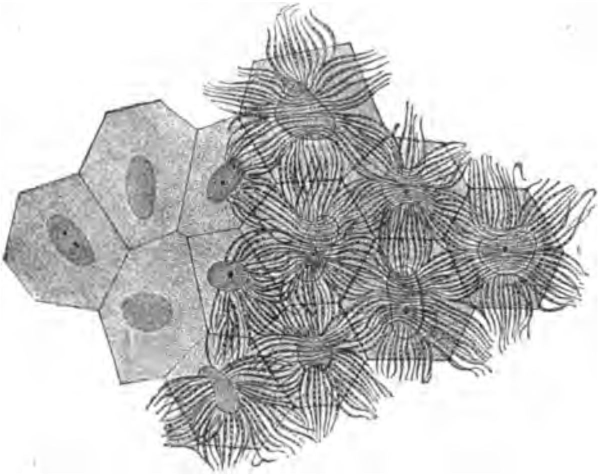

FIG. 126.—CELLS OF ENDOTHELIUM OF MEMBRANE OF DESCEMET OF BIRD'S CORNEA. (Smirnow.)

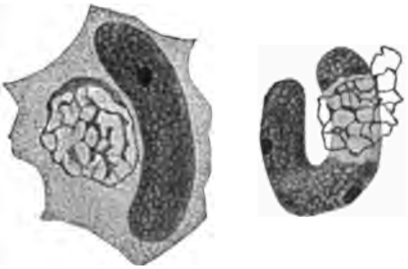

FIG. 127.—A COMPLETE CELL AND A NUCLEUS WITH ATTACHED PARANUCLEUS FROM THE EPITHELIUM OF DESCEMET'S MEMBRANE OF THE CAT. (Greeff, after Ballowitz.)

Near its circumference the membrane of Descemet breaks up into a number of interconnected lamellæ. From these pass three sets of fibres, one to the sclera, another set giving attachment to the ciliary muscle, and a third consisting of fine bundles, which are continued into the substance of the iris and ciliary processes, around the angle of the anterior chamber. To the bundles of fibres prolonged from the circumference of Descemet's membrane into the iris, the name *ligamentum pectinatum* was given by Hueck. They are sometimes known as the 'pillars of the iris,' and are very much more marked in the eyes of some animals (fig. 131, *p*) than in the human eye. The bundles of the ligamentum pectinatum are covered with endothelial cells, continued from Descemet's membrane, but these cells do not stretch

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[1] Ballowitz, Arch. f. mikr. Anat. lvi. 1900; and Anat. Anz. Bd. 18.

[2] Smirnow, Intern. Monatschr. f. Anat. u. Physiol. vii. 1890; Nuel and Cornil, Arch. de biol. x. 1890.

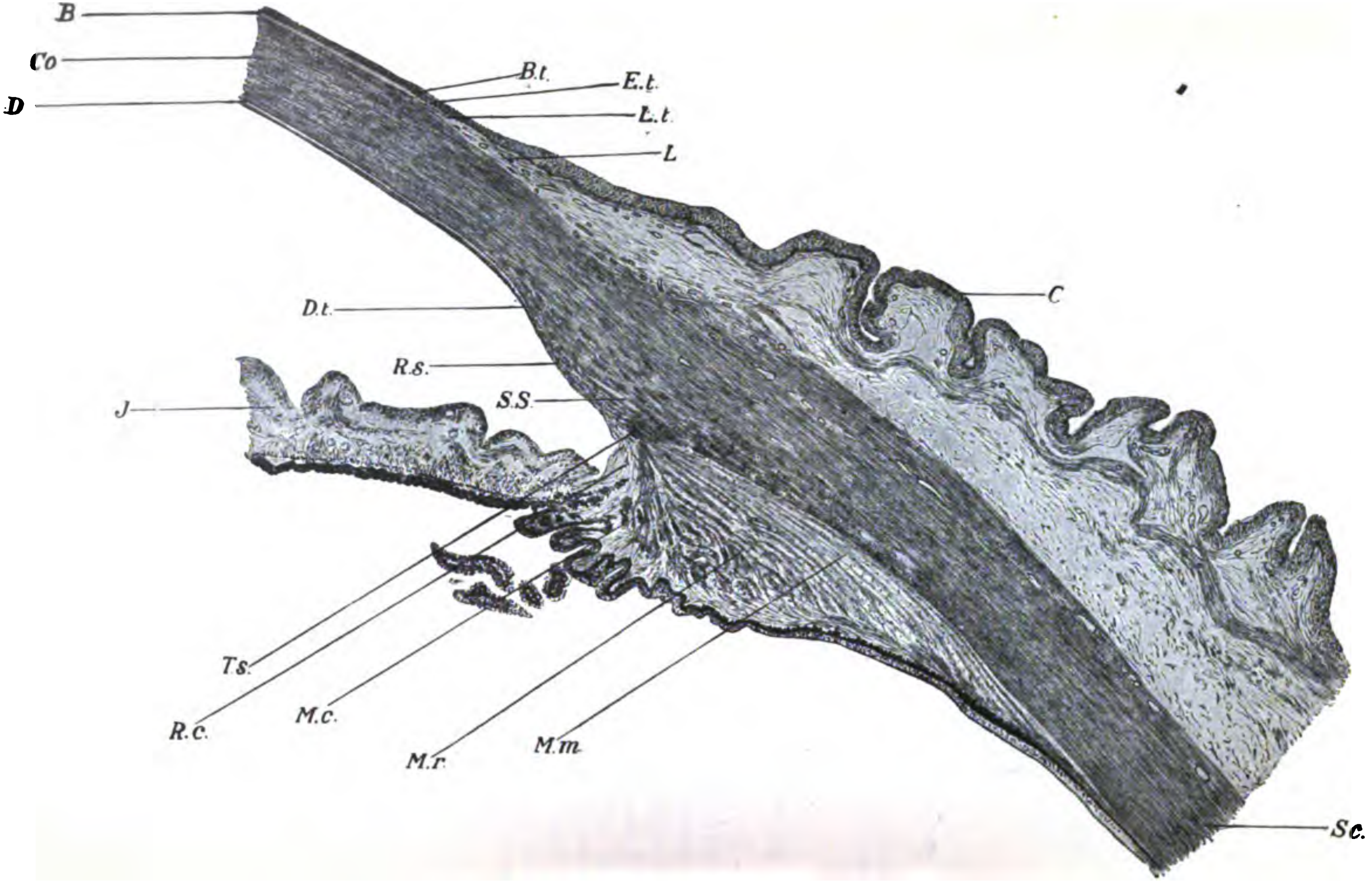

FIG. 128.—SECTION THROUGH ANGLE OF ANTERIOR CHAMBER AND ADJACENT STRUCTURES, FROM THE EYE OF A MAN TWENTY-THREE YEARS OF AGE. Magnified 27 times. (H. Virchow.)

B, Bowman's membrane, terminating near edge of cornea at *B.t.*; *C*, conjunctiva; *Co*, cornea propria; *D*, membrane of Descemet, terminating at *D.t.*, where it disappears in the loose tissue of the ligamentum pectinatum; *E.t.*, epithelium of cornea, near its passage into the conjunctival epithelium; *L*, limbus conjunctivæ, terminating at *L.t.*; *M.m*, meridional fibres of the ciliary muscle; *M.r.*, its radial fibres; *M.c.*, its circular fibres; *R.s.*, scleral part of ligamentum pectinatum; *T.s.*, scleral prominence at attachment of ciliary muscle; *R.c.*, uveal part of ligamentum pectinatum passing round the angle of the anterior chamber into the iris and ciliary processes; *S.S.*, canal of Schlemm; *Sc.*, sclera.

across the *intervals* between the bundles, so that the cavity of the aqueous chamber is prolonged into and freely communicates with a number of spaces traversed and broken up by the bundles (figs. 129, 130). These spaces are much more distinct in many animals, and in some take the form of a considerable cavity, placed at the angle of the anterior chamber, and termed *space of Fontana.* Somewhat more deeply situated in the substance of the sclerotic, close to its junction with the cornea, is a circular canal, often double, or even multiple, and when single generally elliptical in section. This is the *sinus circularis iridis*, *sinus venosus scleræ* or *canal of Schlemm* (fig. 128 *S.S.*; figs. 129, 130). It is in fact a sinus-like vein, which receives blood not only from the episcleral veins, but also from those of the ciliary muscle.

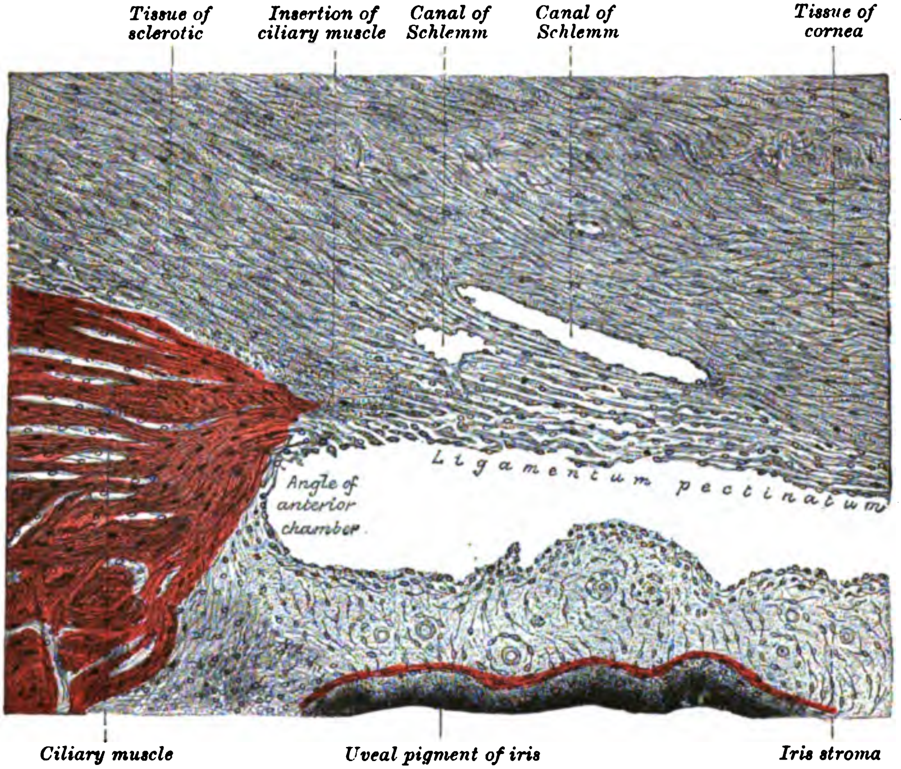

FIG. 129.—SECTION (FROM THE EYE OF AN ADULT) SHOWING THE RELATIONS OF THE CILIARY MUSCLE TO THE SCLEROTIC AND IRIS, AND THE CAVERNOUS SPACES NEAR THE ANGLE OF THE ANTERIOR CHAMBER. (E. A. Schäfer.)

The figure, which is copied from a photograph, includes only a small portion of the ciliary muscle, the fibres of which are seen to be converging to a point immediately anterior to the angle of the anterior chamber. Here they are attached through the medium of a bundle of fibrous tissue of the sclerotic (consisting mainly of circular bundles) to the outer part of the ligamentum pectinatum, which forms a loose tissue with open meshes lying between the canal of Schlemm and the anterior chamber. To the right of the figure the fibres of the ligamentum pectinatum are seen to be gradually converging towards the posterior surface of the cornea, and somewhat beyond the part shown in this figure they merge into the membrane of Descemet. The canal of Schlemm is double in this section. The endothelial-lined spaces between the fibres of the ligamentum pectinatum communicate with the anterior chamber.

The canal of Schlemm appears to communicate with the spaces between the fibres of the ligamentum pectinatum, and through these with the aqueous chamber of the eye (Schwalbe).

But the canal of Schlemm is undoubtedly in communication with the *veins* of the anterior part of the sclerotic, and forms a part of the venous system of the globe. If, therefore, the above-described communication exists, the aqueous chamber must also communicate with the veins. In support of this, it was stated by Schwalbe that both the spaces and the veins become filled with coloured fluid when this is injected into the anterior chamber. But, according to Leber, the results obtained by Schwalbe were due to a diffusible colouring-matter having been employed for filling the anterior chamber. Leber affirmed that when a non-diffusible one is used it never penetrates into the canal of Schlemm, which is simply a large circular vein, or a collection of two or three plexiform veins uniting at frequent intervals into one trunk. It can not only be injected along with the blood-vessels, but can often be seen in sections to contain blood; indeed, Fuchs observed blood in it during life. Nevertheless, fluid may pass with extreme readiness from the anterior chamber into these veins, and this is the case even with Berlin blue, which is not diffusible (Gutmann). This, however, only occurs when the pressure in the aqueous humour is subnormal, as after death and after escape of some of the fluid.[1] The readiness of passage of aqueous into this vein is comparable with the passage of lymph through the arachnoid villi into the venous sinuses of the dura mater.

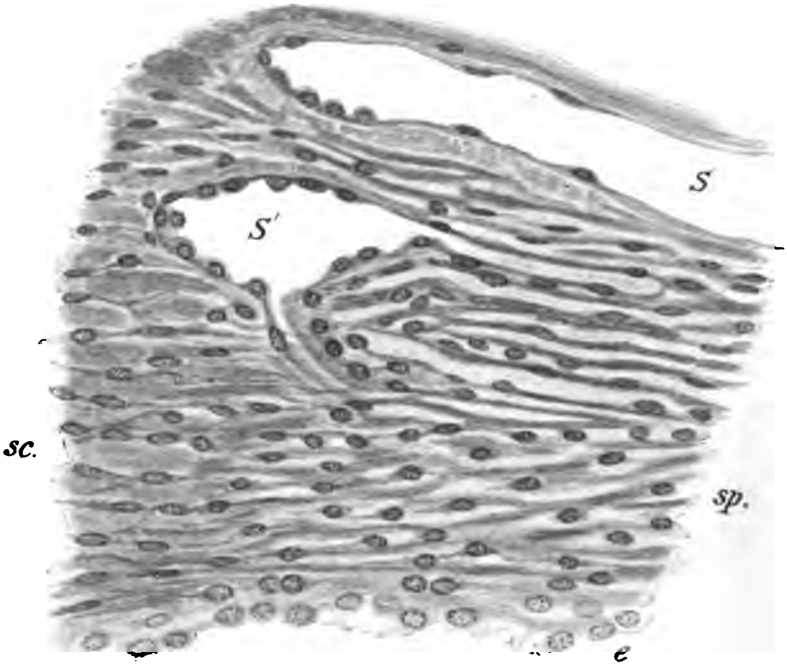

Fig. 130.—Part of the section represented in fig. 129, more highly magnified. $\frac{400}{1}$. (E. A. Schäfer.)

S, *S′*, canal of Schlemm, here double; *sc.*, dense fibrous tissue of sclerotic ring; *e*, endothelium-cells which are continuous with those of the membrane of Descemet; *sp.*, spongy tissue of ligamentum pectinatum. The interstices of this tissue appear to communicate on the one hand with the aqueous chamber and on the other with the canal of Schlemm.

The study of the development of the eye shows that the loose tissue which represents the space of Fontana in animals, as well as the endothelium of Descemet's membrane and the membrane itself, belong to a vascular layer of mesoderm which is continuous with the choroidal layer of the embryonic eye, but which, as development proceeds, becomes separated from the vascular layer of the choroid coat (iris and pupillary membrane), owing to the formation of the anterior chamber; it then comes to form part of the cornea. But in no stage of development do blood-vessels normally penetrate into the cornea (Leber).

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[1] For the literature, as well as an account of the history of this question, see Leber, 'Die Cirkulations- und Ernährungsverhältnisse des Auges,' in Graefe-Saemisch, Handbuch der gesammten Augenheilkunde (2nd ed.), 1903. The most recent experiments and observations on this subject are those of Leber and Pilzecker, Arch. f. Ophth. Bd. lxiv. 1906.

Vessels and nerves.—In a state of health the cornea is not provided with blood-vessels, except at the circumference, where the capillaries of the conjunctiva and sclerotic end in loops, superficial and deep; some of the latter accompany the nerves a certain distance, but hardly any penetrate the actual corneal substance. Neither are any lymphatic vessels discoverable, although the channels in which the nerves run, and which are lined with flattened cells and are indirectly in connexion with the cell-spaces, may be concerned in the conveyance of lymph. This fluid may also pass away by the lymphatics of the conjunctiva, which begin close to the margin of the cornea.

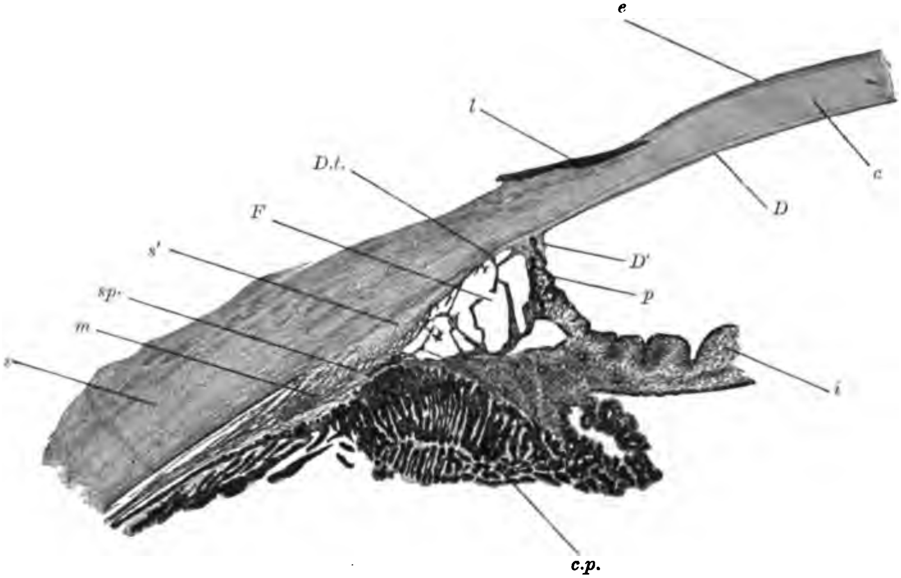

FIG. 181.—SECTION THROUGH THE ANGLE OF THE ANTERIOR CHAMBER OF THE HORSE. $\frac{8}{1}$.
(H. Virchow.)

c, cornea; *e*, its epithelium, pigmented at the limbus, *l*; *D*, membrane of Descemet; *D'*, its continuation over *p*, one of the pillars of the iris; *D.t.*, termination of Descemet's membrane; *i*, iris; *F*, space of Fontana; *s*, sclera; *m*, ciliary muscle; *sp.*, spongy tissue continued from that in the space of Fontana; *s'*, scleral prominence; *c.p.*, ciliary process cut tangentially, and showing sections of secondary folds.

The *nerves*, on the other hand, are very numerous. Derived from the plexus formed of the short and long ciliary nerves, they enter the fore-part of the sclerotic; and those destined for the anterior layers and the epithelium, from forty to fifty in number,[1] form a plexus which surrounds the margin of the cornea (*plexus annularis*). Continued into the fibrous part of the cornea, partly directly, partly by passing to the adjacent conjunctiva, they retain their medullary sheath for 1 to 2 mm., and then, becoming non-medullated, ramify and form a plexus in the laminated structure, near the anterior surface. From this *fundamental plexus* branches pass obliquely through the anterior homogeneous lamina, where they divide into pencils of fibrils, whose general direction is towards the centre of the cornea; the bundles of fibrils join with one another to form a much finer and closer plexus immediately beneath the epithelium. From this *subepithelial plexus* fine varicose fibrils pass among the epithelium-cells, and form here a terminal ramification which extends almost to the free surface (figs. 132 and 133). According to Dogiel, some of the end-twigs terminate in flattened or bulbous enlargements between the epithelial cells.

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[1] Dogiel, Anat. Anz. 1890.

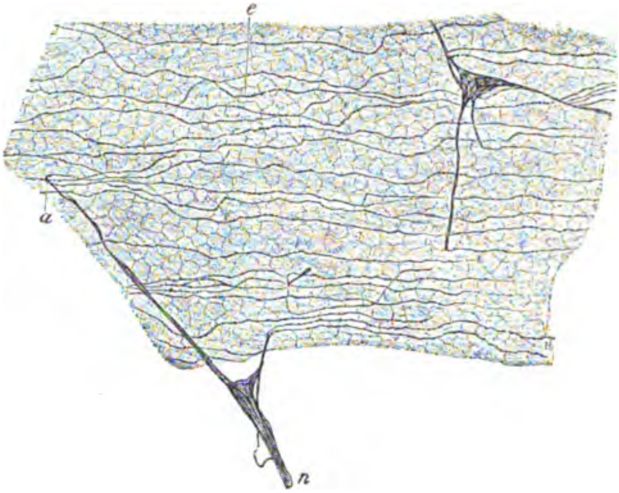

FIG. 132.—CORNEA OF RABBIT, VIEWED ON THE FLAT, SHOWING THE SUBEPITHELIAL PLEXUS. Chloride of gold preparation. (Ranvier.)

n, nerve of fundamental plexus, giving off pencils of fibrils, *a*, to form the subepithelial plexus, *e*.

In addition to the nerves which are destined for the epithelium, others, from twenty to thirty in number, for the proper substance of the cornea, come off from the ciliary plexus and, passing in front of the canal of Schlemm, enter the more posterior part of the cornea and, after joining to form plexuses, the cords of which are still composite, eventually form, in and among the laminæ, a terminal ramification of ultimate fibrils, the meshes of which are more open than those of the intra-epithelial network. Some of these fibres which enter the posterior part help in the formation of the fundamental plexus (see above) of the more central area of the cornea, from which the subepithelial and intra-

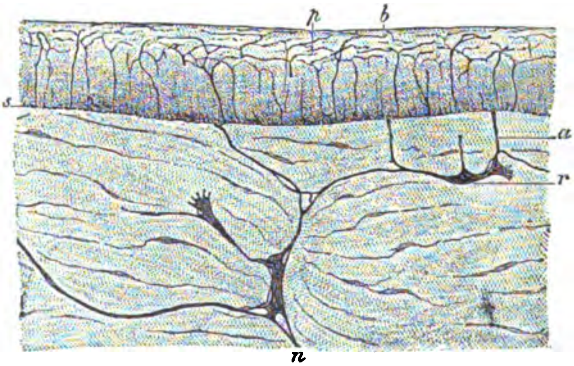

FIG. 133.—VERTICAL SECTION OF RABBIT'S CORNEA. Chloride of gold preparation. (Ranvier.)

n, *r*, part of fundamental plexus; *a*, vertical branch passing to subepithelial plexus, *s*; *p*, *b*, intra-epithelial ramification.

epithelial nerves of this part are derived. An actual connexion of the nerves with the corpuscles of the cornea probably never occurs; although, since fine nerve-fibrils run in the anastomosing cell-spaces, they come into close connexion with the corpuscles and their processes, and they have on this account been supposed by some observers to be actually continuous with them. In the marginal zone of the cornea some of the nerve-fibres end in plexiform glomeruli, and others in flattened expansions (Ciaccio, Dogiel). In some animals there is a close plexus of fine fibrils immediately beneath the membrane of Descemet (fig. 134).

The larger branches of the nerves are covered with a sheath of thin cells. At the points of junction of the plexuses nuclei are frequently seen, but whether these belong to the ensheathing cells or are interpolated in the course of the nerve-fibres is uncertain.

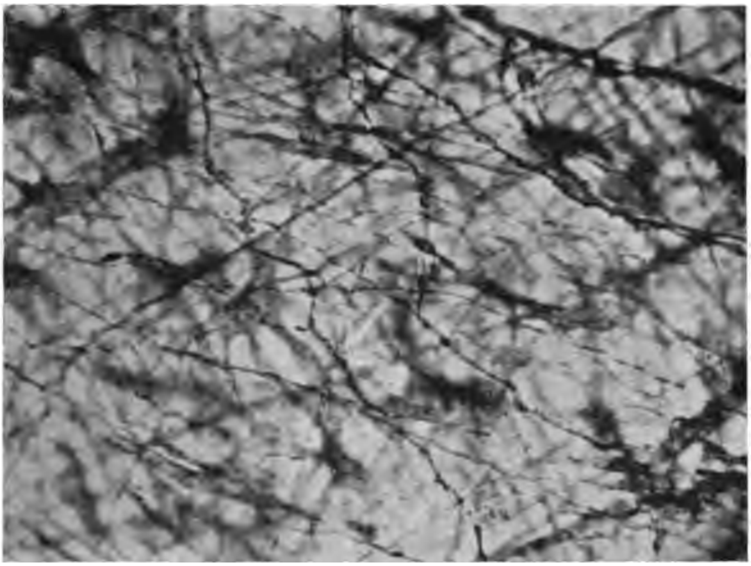

FIG. 184.—NERVES AND CORPUSCLES OF THE SUBSTANTIA PROPRIA OF THE POSTERIOR LAYERS OF THE FROG'S CORNEA.
Photographed from gold-chloride preparation. (E. A. Schäfer.)

THE CHOROID COAT (TUNICA VASCULOSA).

The vascular coat of the eye (*tunica uvea s. vasculosa*) lies within the corneo-sclerotic coat, and consists of two parts, which are continuous with one another—viz. the choroid and iris. The choroid is applied to the inner surface of the sclerotic, and is firmly attached to the inner surface of the retina; the iris is fixed only at its circumference, otherwise floating freely in the aqueous humour immediately in front of the lens, with which it comes lightly into contact, and separated from the cornea by the depth of the anterior chamber.

The **choroid coat** (*tunica choroidea* or *chorioidea*) is a dark-brown membrane (black in many animals) lying between the sclerotic and the retina. Anteriorly it is continued into the iris, but before it passes into this it forms a number of radial thickenings named *ciliary processes*, disposed in a circle and projecting into the anterior part of the vitreous humour. These give attachment to the suspensory ligament of the lens. The choroid coat is thickest behind, around the aperture for the optic nerve. The outer surface is connected to the sclerotic by loose connective tissue and by vessels and nerves which pass obliquely across a lymph-space which otherwise serves to separate the two tunics. The inner surface, which is smooth, is covered by the hexagonal pigmented cells of the retina. These, when the retina is detached, generally remain partly adherent to the choroid, and were formerly described as belonging to that coat, but they are now known to be intimately related, both morphologically and physiologically, to the retina. The ciliary part of the choroid with the ciliary processes is often spoken of as the ciliary body (*corpus ciliare*).

The *ciliary processes* (fig. 136), about seventy in number, are arranged meridionally, and together form a circle. They consist of larger and smaller thickenings without regular alternation. Each of the larger ones, measuring about 2·5 mm. in length and 0·6 mm. in depth, forms a rounded projection at its inner (anterior) end, which is free from the pigment which invests the rest of the structure; but externally they gradually taper, and become lost. The smaller processes are only half as deep as the others, and about one-third as numerous. At and near the inner ends the processes are connected by lateral projections.

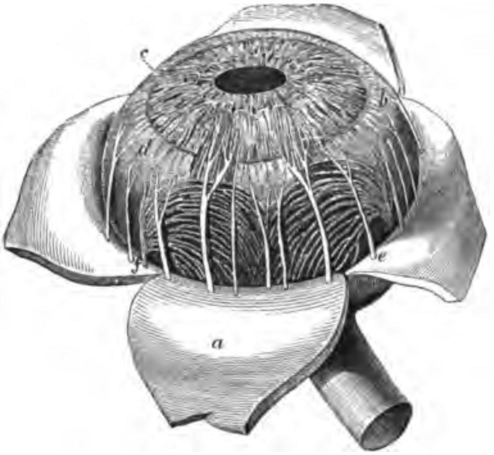

FIG. 135.—CHOROID MEMBRANE AND IRIS EXPOSED BY THE REMOVAL OF THE SCLEROTIC AND CORNEA. Twice the natural size. (After Zinn.)

a, part of the sclerotic thrown back; *b*, ciliary muscle; *c*, iris; *e*, one of the ciliary nerves; *f*, one of the vasa vorticosa or choroidal veins.

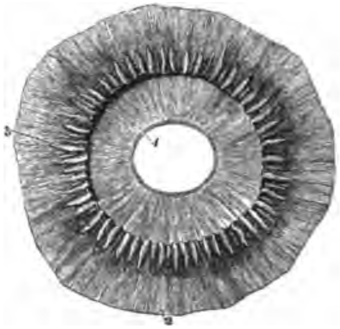

FIG. 136.—CILIARY PROCESSES AS SEEN FROM BEHIND. Twice the natural size.

1, posterior surface of the iris, with the sphincter muscle of the pupil; 2, anterior part of the choroid coat; 3, ciliary processes.

Structure of the choroid.—The choroid consists mainly of blood-vessels united by delicate connective tissue, which contains numerous large ramified and pigmented cells.

Externally the choroid is bounded by a non-vascular membranous layer corresponding with the *lamina fusca* of the sclerotic, and known as the *lamina supra-choroidea*. This is composed of thin membranes of a homogeneous aspect, but pervaded by networks of fine elastic fibres, and covered by large flat cells. It contains also large pigment-cells dispersed irregularly or arranged in patches, with considerable intervals free from pigment-cells; and lymphoid cells may occur in it here and there singly or in groups (fig. 137). It is loosely united to the lamina fusca by vessels and bands of connective tissue enclosing pigment-cells, and the two laminæ as well as the uniting structures are coated with endothelium, a lymph-space being thus formed between the sclerotic and choroid. According to Schwalbe, this space communicates, at the places where the vessels and nerves pierce the sclerotic, with that of the capsule of Tenon, especially by perivascular lymph-channels round the venæ vorticosæ. Lang [1] was unable to confirm the existence of these lymphatic channels.

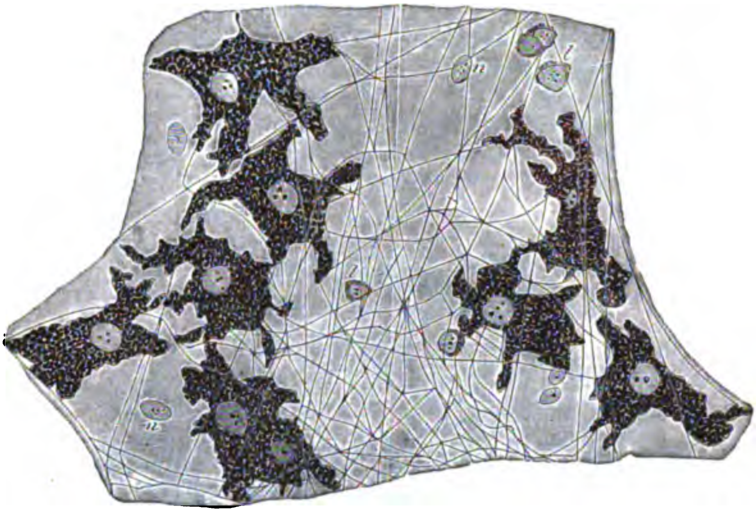

FIG. 137.—A SMALL PORTION OF LAMINA SUPRA-CHOROIDEA. Highly magnified. (E. A. Schäfer. *n*, nuclei of endothelial cells (the outlines of the cells are not indicated); *l*, lymph-cells.

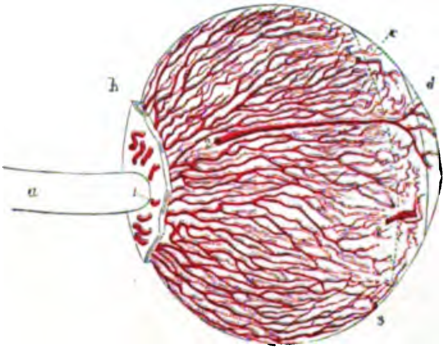

FIG. 138.—LATERAL VIEW OF THE ARTERIES OF THE CHOROID AND IRIS. (From Arnold.)

a, optic nerve; *b*, part of the sclerotic left behind; *c*, region of ciliary muscle; *d*, iris; 1, posterior ciliary arteries piercing the sclerotic and passing along the choroid; 2, one of the long ciliary arteries; 3, anterior ciliary arteries.

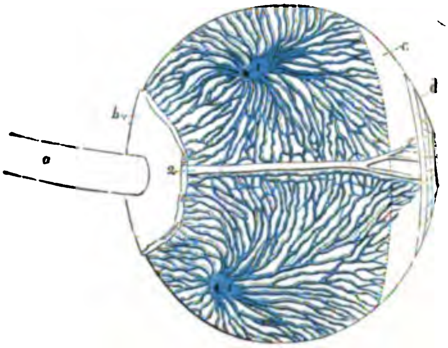

FIG. 139.—LATERAL VIEW OF THE VEINS OF THE CHOROID. (From Arnold.)

1, 1, two trunks of the venæ vorticosæ at the place where they leave the choroid and pierce the sclerotic coat. The other lettering as in fig. 138.

The **choroid proper** resembles in general structure the lamina supra-choroidea, but contains in addition a very large number of blood-vessels. From a difference in the fineness of these constituent vessels, it resolves itself into two strata, outer and inner; the former containing the larger branches, and the latter the capillary ramifications. A layer of connective tissue, including many elastic fibres, which unites the two strata and is nearly free from pigment, is sometimes described as a third or intermediate part.

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[1] Wiener Sitzungsb. xcix.

The **outer part** of the coat (*lamina vasculosa*) contains the larger branches of the vessels. From four to six *short posterior ciliary* arteries, derived from the ophthalmic, accompany the optic nerve, dividing as they pass into numerous branches which pierce the sclerotic obliquely close to the entrance of the optic nerve (figs. 138 and 140), and then divide dichotomously into branches which are directed at first forwards, but soon bend inwards to end in the capillary layer. Some of the arteries form an arterial circle around the optic-nerve entrance. Two *long posterior ciliary arteries* pierce the sclerotic farther forwards, one on each side; they are accompanied by ciliary nerves and pass to the iris and ciliary body. Each artery as it traverses the sclerotic lies in a sort of canal in its substance. The *anterior ciliary arteries*, which are derived from the vessels to the four recti muscles, pierce the sclerotic not far behind its junction with the cornea. All these give fine branches to the sclerotic as they are passing through it. The long posterior and the anterior ciliary arteries supply the ciliary body and iris; the choroid proper is supplied by the short posterior ciliary arteries. The veins lie external to the arteries and are disposed in curves (*posterior ciliary veins, venæ vorticosæ*) as they converge to four or five principal trunks (fig. 139, 1, *f*; fig. 140) (generally two above and two below, passing

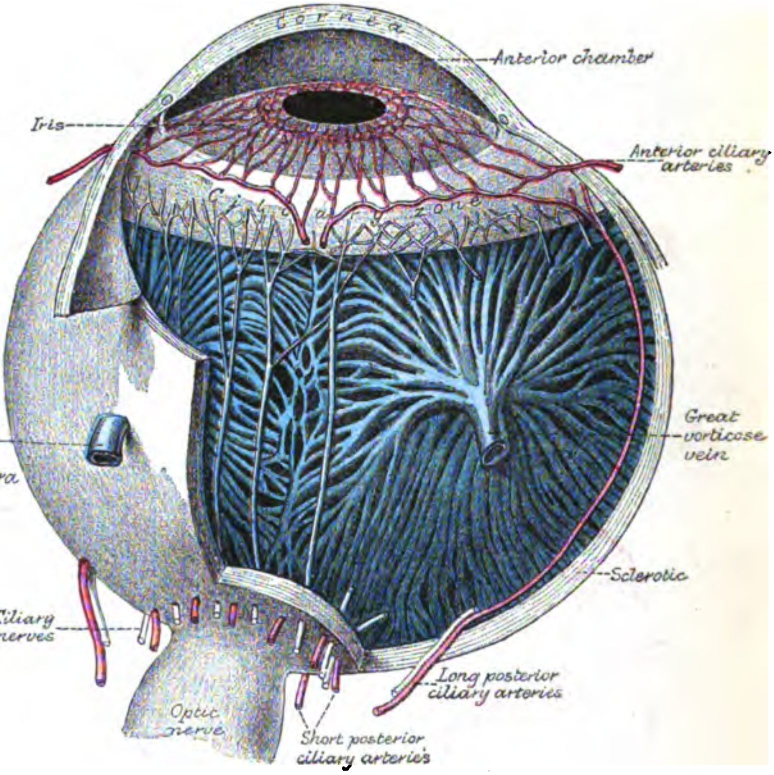
Cornea
Anterior chamber
Iris
Anterior ciliary arteries
Ciliary zone
Great vorticose vein passing through sclera
Great vorticose vein
Sclerotic
Ciliary nerves
Long posterior ciliary arteries
Optic nerve
Short posterior ciliary arteries

FIG. 140.—DIAGRAM SHOWING THE PRINCIPAL NERVES AND BLOOD-VESSELS OF THE EYEBALL. (Testut.)

respectively into the superior and inferior ophthalmic veins) which pierce the sclerotic about half-way between the margin of the cornea and the entrance of the optic nerve. The *anterior ciliary veins*, which collect some of the blood from the ciliary muscle, are finer than the corresponding arteries, which they accompany to join the vessels of the recti muscles. But most of the blood of the corpus ciliare and iris, as well as that of the choroid proper, passes away by the venæ vorticosæ. In the intervals between the vessels the choroid coat contains elongated and stellate pigment-cells. The veins, like those of the pia mater, have no muscular tissue and no valves; they are enclosed by an adventitious sheath, between which and the endothelium which forms the wall of the vein a lymph-space has been described in the form of a perivascular sheath. The arteries have, besides the ordinary circular muscular fibres, strands of longitudinally disposed plain muscular tissue in their adventitia. As the venæ vorticosæ pass through the sclerotic they are ensheathed by a prolongation of suprachoroideal tissue (Fuchs).

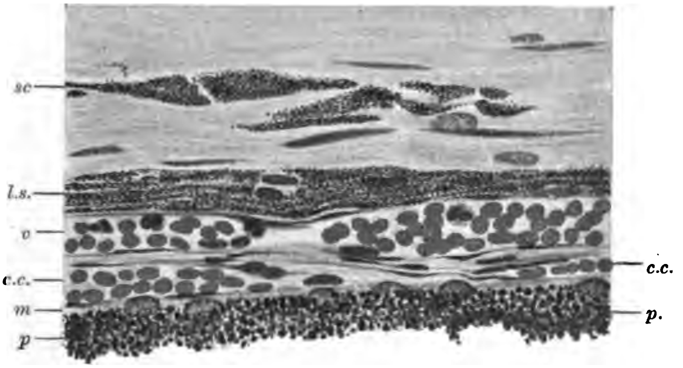

FIG. 141.—SECTION OF CHOROID COAT, HUMAN, WITH A PART OF THE SCLERA AND A PORTION OF THE PIGMENT-LAYER OF THE RETINA ATTACHED. $\frac{400}{1}$. (E. A. Schäfer.)

sc, sclera: the indicating line points to some of the pigment-cells which occur in this innermost part of the sclera; *l.s.*, lamina suprachoroidea; *v*, layer of choroid containing the larger vessels; *c.c.*, chorio-capillaris; *m*, membrana basilaris; *p*, retinal pigment-epithelium cells, fragments of which are still attached to this membrane.

The **inner part** of the choroid coat (*lamina chorio-capillaris*, fig. 141, *c.c.*) is formed mainly by the capillaries of the choroidal vessels. From the ends of the arteries the capillaries radiate and form a network the meshes of which are closer than in almost any other texture, being especially close and regular at the back of the eyeball, near the yellow spot. Farther forward the meshes become more elongated. The network reaches as far forwards as the ora serrata, where it joins that of the ciliary body.

The capillaries are imbedded in a soft almost homogeneous tissue, devoid of pigment-cells, and are stated to be enclosed within extensions of the perivascular lymph-spaces of the choroidal veins. But, according to Alexander,[1] the lymph-spaces lie between the blood-capillaries.

The veins begin by the convergence of the choroidal capillaries in a whorl-like manner (fig. 142) to form venous tributaries, which themselves converge again in a similar manner to form the large whorled veins or venæ vorticosæ, by which the blood is conveyed away from the choroid coat.

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[1] Arch. f. Anat. 1889.

On the inner surface of the choroid is a structureless or finely fibrillated transparent membrane, the *membrana basalis* or *membrane of Bruch* (fig. 141, *m*), which lies next to the pigmentary layer of the retina, and, especially anteriorly in the region of the ciliary processes, has on its outer surface numerous microscopic reticulations. In the young subject it is separable into two layers.[1] It measures ·002 mm. in thickness in the adult[2] and tends to become thickened as age advances.

Immediately external to the membrana basilaris, between it and the lamina chorio-capillaris, is a dense layer of elastic tissue with which the numerous elastic fibres which traverse the rest of the choroid are connected.[3]

Tapetum.—In many animals a structure occurs in the choroid coat which produces an iridescent appearance when the eye is looked into through the pupil. Two kinds of tapetum are met with (Brücke)—viz. the *tapetum fibrosum*, which is found in ruminants and pachyderms, and is produced by a development of connective-tissue fibres; and the *tapetum cellulosum* occurring in carnivora (and in fish) and formed of flattened epithelioid cells containing innumerable small crystals. The tapetum lies in a boundary-zone between the pars vascularis and the chorio-capillaris. The ordinary retinal pigment is wanting over these structures, and the light is reflected from them and gives rise to the characteristic glistening appearance of the eye in animals which possess a tapetum.

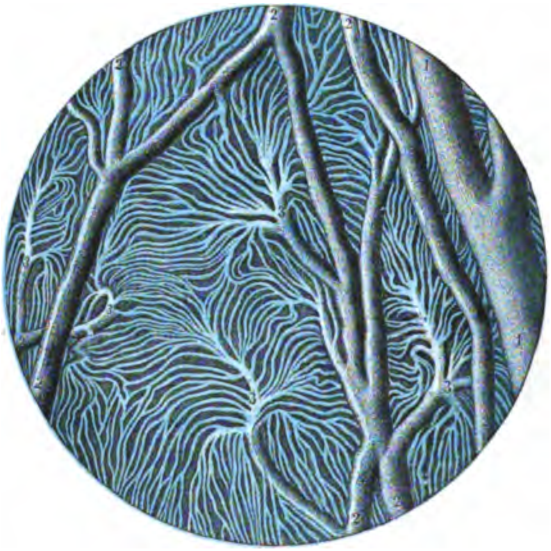

FIG. 142.—INJECTED BLOOD-VESSELS OF THE CHOROID COAT. 80 diameters. (From Sappey.)
1, one of the larger veins; 2, small communicating vessels; 3, branches dividing into the smallest vessels.

The **ciliary region of the choroid coat** embraces the part between the ora serrata of the innermost coat (retina) and the attachment of the iris. The posterior zone of this region, about 4 mm. broad, lies between the ora serrata and the ciliary processes, and is known as the *orbiculus ciliaris*. This part has no chorio-capillaris. Its vessels run parallel with one another, with much elastic tissue between them. The anterior zone is formed by the ciliary processes, which are collectively termed the *corpus ciliare.* In the external part of the ciliary region is the *ciliary muscle,* which was accurately described by Brücke and independently by Bowman.[1]

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[1] Sattler, Arch. f. Ophth. xxii. 1876.

[2] Alexander, Arch. f. Anat. 1889.

[3] Smirnow, Arch. f. Ophth. xlvii. 1898. Sattler (Ibid. xxii. 1876) described the elastic fibres of the choroid as being especially abundant just *outside* the lamina chorio-capillaris. For many other details on the structure of the choroid, see Wolfrum in Arch. f. Ophth. Bd. 67, 1908.

The **ciliary processes** have the same structure as the rest of the choroid; but the capillary plexus of the vessels is less fine, and has meshes with chiefly a longitudinal direction; and the ramified cells, fewer in number, are devoid of pigment towards the free extremities of the folds. The ciliary processes are penetrated for a certain distance by glandular invaginations of the pigmented epithelium which covers their free surface (E. T. Collins, L. Buchanan). These *ciliary glands* probably assist in the secretion of the aqueous humour.

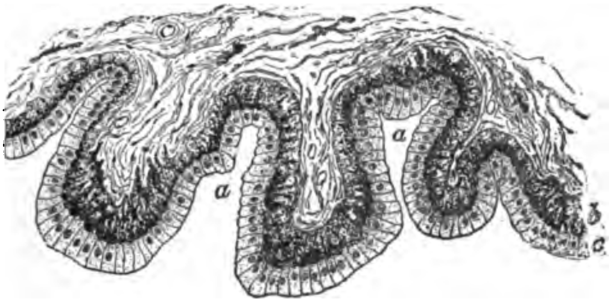

FIG. 143.—SECTION THROUGH THE POSTERIOR PART OF THE CILIARY PROCESSES. Magnified 155 diameters. (Piersol.)

a, a, recesses between the folds or thickenings; *b,* deeper (pigmented) layer of epithelium; *c,* superficial layer of non-pigmented columnar epithelium: these two layers constitute the pars ciliaris retinæ.

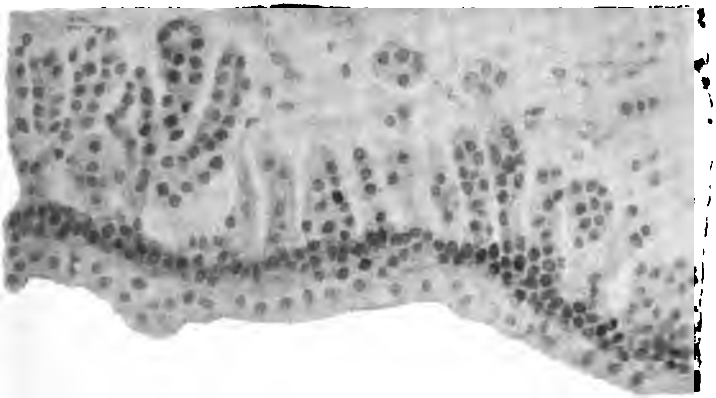

FIG. 144.—GLANDS OF THE CILIARY PROCESSES, AS SEEN AFTER BLEACHING THE PIGMENT IN THE EPITHELIUM WHICH COVERS THE PROCESSES. (E. Treacher Collins.)

The *blood-vessels* of the ciliary processes (fig. 146, *d*) are very numerous; they are derived from the anterior ciliary arteries. Several small arterial branches enter the outer part of each ciliary process, at first running parallel to each other and communicating sparingly. As they enter the prominent folded portion, the vessels become tortuous, subdivide minutely, and inosculate frequently. Finally they form short arches or loops, and turn backwards to pour their contents into the radicles of the veins. On the free border of the fold, one artery, larger than the rest, extends the whole length of each ciliary process, and communicates through intervening vessels with a long venous trunk which runs a similar course on the attached surface. A number of recurrent branches of the arteries of the ciliary body pass backwards into the anterior part of the choroid coat. The veins of the ciliary processes pass backwards into the choroid and help to form the venæ vorticosæ.

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[1] Brücke, Med. Zeitung. 1846; Bowman, Lectures on the Eye, 1847. As early as 1835 W. C. Wallace ('On the Accommodation of the Eye to Distances,' Amer. Journ. of Sci. and Arts, xxvii.) had described muscular fibres in this region, but he places them upon the inner surface of the choroid. He mentions also the existence of circular fibres. See, on the history of this muscle, F. Baker, in Norris and Oliver, 'System of Diseases of the Eye,' 1897.

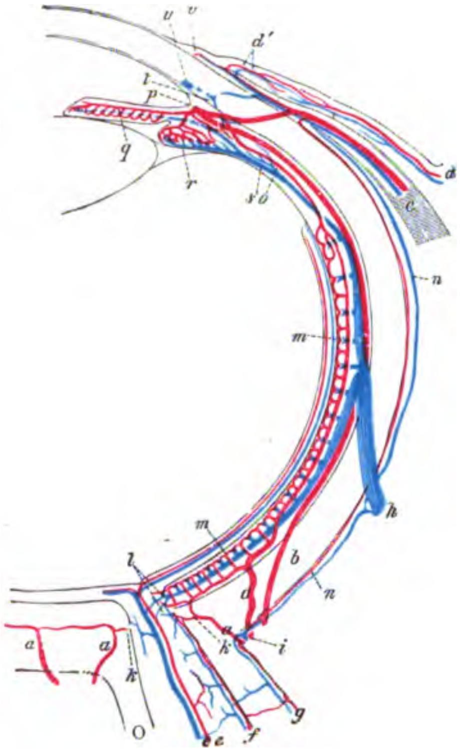

Fig. 145.

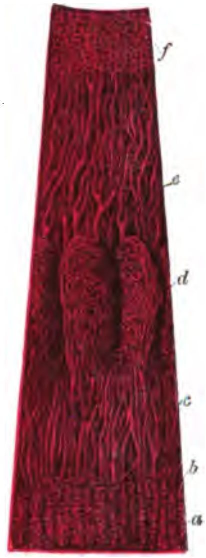

Fig. 146.

Fig. 145.—Diagrammatic representation of the course of the vessels in the eye. Horizontal section. (Leber.) Arteries and capillaries red; veins blue.

O, entrance of optic nerve; *a*, short posterior ciliary arteries; *k*, branch to the optic nerve; *b*, long posterior ciliary arteries; *c*, anterior ciliary vessels; *d*, posterior conjunctival vessels; *d'*, anterior conjunctival vessels; *e*, central vessels of the retina; *f*, vessels of the inner sheath of the optic nerve; *g*, vessels of the outer sheath; *h*, vorticose vein; *i*, short posterior ciliary vein; *l*, anastomosis of choroidal vessels with those of optic nerve; *m*, chorio-capillaris; *n*, episcleral vessels; *o*, recurrent artery of the choroid; *p*, circulus iridis major (in section); *q*, vessels of iris; *r*, vessels of ciliary process; *s*, branch from ciliary muscle to vorticose vein; *t*, branch from ciliary muscle to anterior ciliary vein; *u*, canal of Schlemm; *v*, capillary loop at margin of cornea.

Fig. 146.—Vessels of the choroid, ciliary processes, and iris of a child. Magnified 10 times. (Arnold.)

a, capillary network of the posterior part of the choroid, ending at *b*, the ora serrata; *c*, arteries of the corona ciliaris, supplying the ciliary processes, *d*, and passing into the iris, *e*; *f*, the capillary network close to the pupillary margin of the iris.

Ciliary muscle.—The anterior part of the choroid, opposite the ciliary processes, is considerably thickened. The thickening is triangular in section, and is produced by a zone 6–7 mm. wide of plain muscular tissue, forming the *ciliary muscle.* The main part of this muscle (*fibræ meridionales*) arises

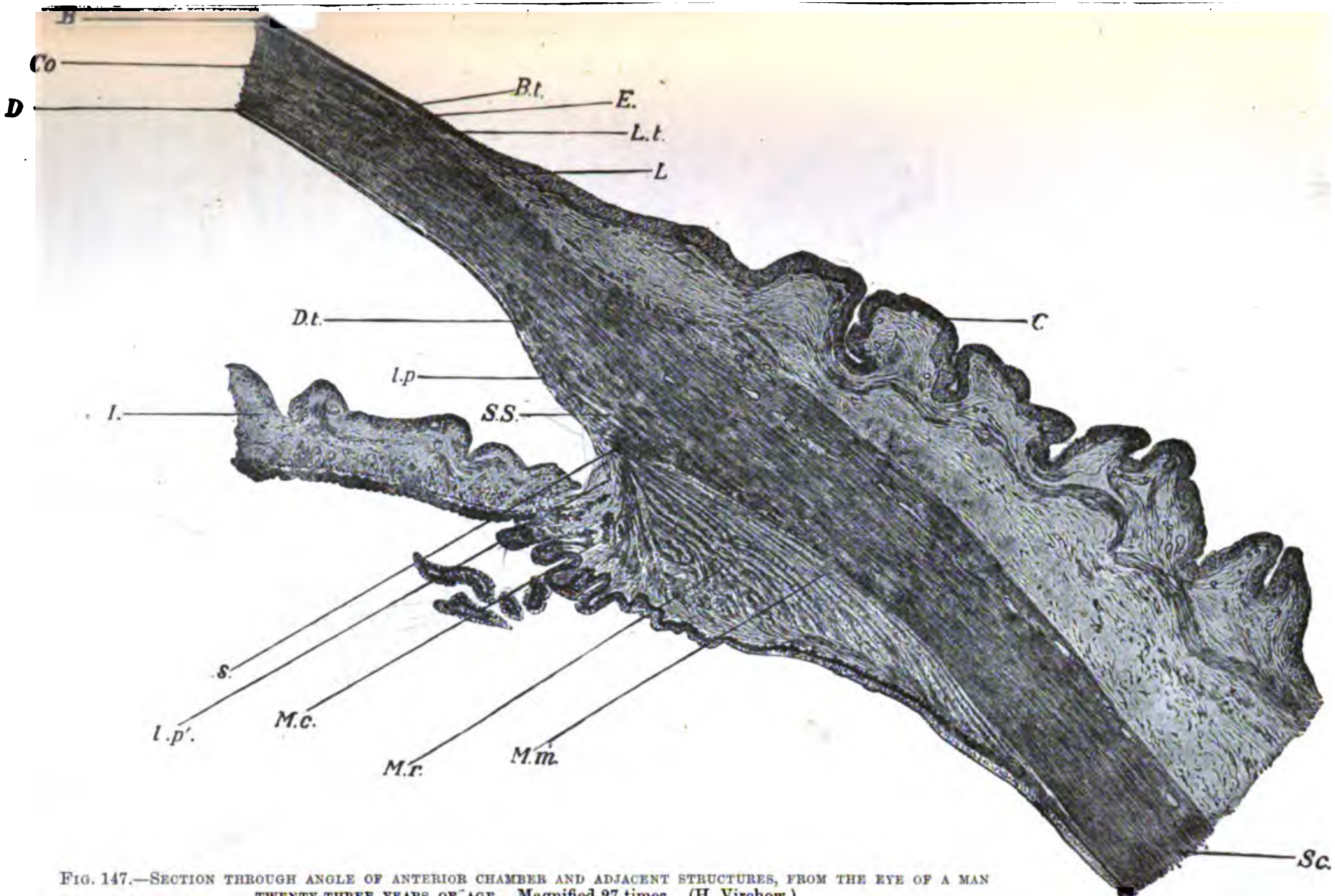

FIG. 147.—SECTION THROUGH ANGLE OF ANTERIOR CHAMBER AND ADJACENT STRUCTURES, FROM THE EYE OF A MAN TWENTY-THREE YEARS OF AGE. Magnified 27 times. (H. Virchow.)

B, Bowman's membrane, terminating near edge of cornea at *B.t.*; *C*, conjunctiva; *Co*, propria of cornea; *D*, membrane of Descemet, terminating at *D.t.*, where it disappears in the loose tissue of the ligamentum pectinatum; *E.*, epithelium of cornea, near its passage into the conjunctival epithelium; *L*, limbus conjunctivæ, terminating at *L.t.*; *M.m.*, meridional fibres of the ciliary muscle; *M.r.*, its radial fibres; *M.c.*, its circular fibres; *l.p*, scleral part of ligamentum pectinatum; *s.*, scleral prominence at attachment of ciliary muscle; *l'.p'.*, uveal part of ligamentum pectinatum passing round the angle of the anterior chamber into the iris and ciliary processes; *S.S.*, canal of Schlemm; *Sc.*, sclera; *I.*, iris.

(figs. 129, 147) by a thin flat expansion from the fore-part of the sclerotic close to the cornea, between the canal of Schlemm and the anterior chamber, its fibres being attached to the bundles of the ligamentum pectinatum which occupy this position. The muscular fibres, spreading out as they pass backwards (fig. 147, *M.m.*, *M.r.*), are inserted into the choroid coat opposite to the ciliary processes, and partly farther back. At their insertion the fibres pass obliquely and inter-cross so as to form peculiar stellate figures. According to Waldeyer, a small portion (the outermost) is sometimes inserted into the sclerotic coat,[1] but this must be very rare, for the sclerotic always becomes detached with the greatest ease from this part of the muscle. The radial fibres pass towards the iris into a ring of fibres (*fibræ circulares*) (fig. 147, *M.c.*), which have a circular course around the insertion of the iris. This set forms the *circular ciliary muscle* of H. Müller and is much developed in hypermetropic eyes, but atrophied, or even absent altogether, in myopic (Iwanoff) (fig. 148). It was formerly described as the ciliary ligament. In birds the ciliary muscle contains cross-striped muscular fibres. When the ciliary muscle contracts it tends to draw the choroid and ciliary processes forwards and inwards. The suspensory ligament of the lens is thus relaxed and the lens becomes more convex.[2] The ciliary muscle receives blood-vessels from the long ciliary arteries and from the anterior ciliary, which form an incomplete anastomotic circle within it. The capillary network of the circle has rectangular meshes. The veins pass for the most part into those of the ciliary body, but some enter the sclerotic and come into communication with the canal of Schlemm and the anterior ciliary veins.

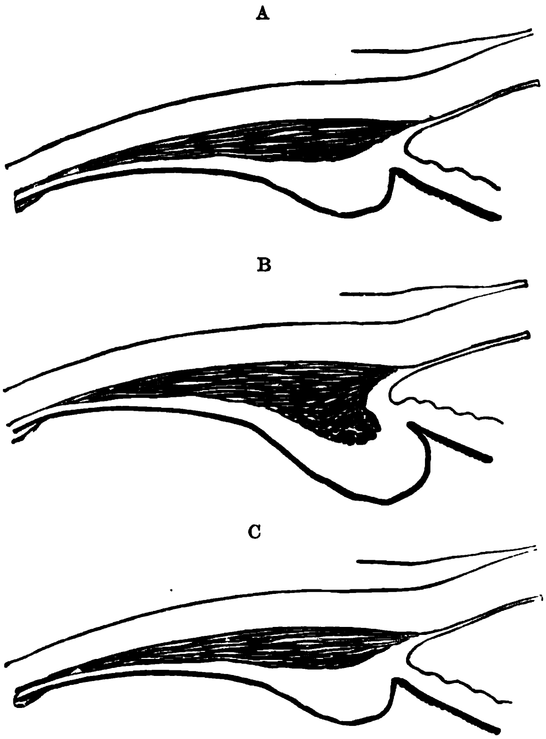

Fig. 148.—Diagrams showing the comparative development of the circular fibres of the ciliary muscle in

A, the normal or emmetropic eye; B, the hypermetropic eye; and C, the myopic eye. (Fuchs.)

The *nerves* of the choroid will be described with those of the iris.

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[1] This part, if present, may be the homologue of an important portion of the accommodation mechanism of birds which is known as the Cramptonian muscle, and is composed of striated muscular fibres.

[2] See on the structures concerned in the mechanism of accommodation in vertebrates, Th. Beer in Pflüger's Archiv, Bde. 53, 58. On the anatomical changes accompanying accommodation, Heine in Arch. f. Ophth. xlix. 1899. On the action of the ciliary muscle, see the article 'Vision,' by W. H. Rivers, in Schäfer's Text-book of Physiology, 1900, vol. ii. p. 1038.

THE IRIS.

The **iris** is the contractile and coloured membrane which is seen behind the transparent cornea, and gives the tint to the eye. In its centre it is perforated by an aperture—the *pupil.*

At its circumferential border, which is nearly circular, the iris is continuous with the choroid, and, by the ligamentum pectinatum, with the cornea; the free inner edge is the boundary of the pupil. The iris measures about 11 mm. across, and, in a state of rest, about 5 mm. from the circumference to the pupil, which is slightly nearer the nasal side: its thickness is about 0·4 mm. The anterior surface is marked by waved lines converging towards the pupil, near which they join in a series of irregular elevations; and, internal to these, other finer lines pass to the pupil. The appearance of lines is produced by the radially disposed blood-vessels. The posterior surface is covered with dark pigment-cells (*pars retinalis*), and is marked by a number of fine converging folds or thickenings prolonged from the ciliary processes.

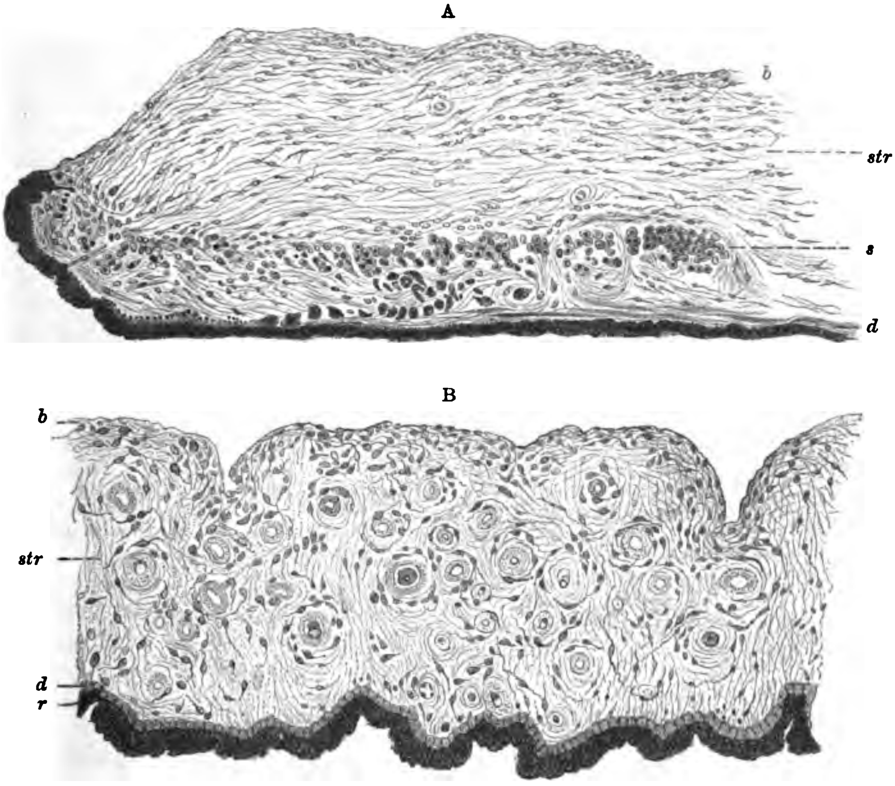

FIG. 149.—TWO SECTIONS OF THE HUMAN IRIS: A, RADIAL; B, TAKEN ACROSS THE RADII. Highly magnified. (G. Retzius.)

b, basement-membrane and endothelium of anterior surface; *str*, stroma; *s*, bundles of fibres of sphincter pupillæ, cut across (in A); *d*, layer of dilatator pupillæ; *r*, pigment (pars retinalis iridis).

The **pupil**, nearly circular in form, is constantly varying in size during life (from 1 mm. to 8 mm.). It is habitually wider in young than in old persons.

Structure of the iris.—A delicate connective tissue forms the framework or stroma of the iris (fig. 149). It contains also very numerous vessels and nerves. The endothelial layer of the membrane of Descemet (fig. 129) is continued from the margin of the cornea over the front of the iris; its cells are smaller and more granular than those which cover the membrane of Descemet, but are otherwise similar. Depressions of some size have been described in this anterior surface of the iris (Fuchs, Nuël and Cornil) and an important function in connexion with the drainage of aqueous humour has been ascribed to them. They have been termed *stomata*, but it is doubtful if they are analogous to the openings of the same name which occur in serous membranes and which communicate with subjacent lymphatics. The posterior surface of the iris is covered by two layers of pigmented epithelium which is often known as the *uveal epithelium.* The superficial layer is composed of short columnar or cubical cells and the deeper layer of flattened cells, looking spindle-shaped in meridional sections of the iris. These spindle-shaped pigmented cells have sometimes been taken for plain muscular tissue belonging to the dilatator pupillæ, but the muscular stratum is quite distinct from them (fig. 151). This pigment-epithelium is continuous with the (retinal) pigmentary layer covering the ciliary processes, and ends abruptly at the margin of the pupil; it forms what is known as the *pars retinalis iridis* (*pars iridica retinæ*), as distinguished from the *pars choroidalis* or stroma.

The *stroma* consists of cells and fibres of connective tissue, the latter directed for the most part radially towards the pupil. It contains few elastic fibres except those in the walls of the vessels. In the substance of the iris anteriorly and throughout its thickness are variously shaped ramified pigment-cells like those in the choroid. The pigment contained in them is yellow, or of lighter or darker shades of brown, according to the colour of the eye. The colour of the iris depends partly on the pigment in the cells of the pars retinalis, partly on that in the stroma cells; in the eye of the infant and in the different shades of blue eye it arises from the black pigment of the posterior surface appearing more or less through the stroma, which in such cases is only slightly coloured or is colourless. But in the black, brown, and grey eye the colour is due to, or affected by, the pigment-cells scattered through the substance of the stroma itself.[1]

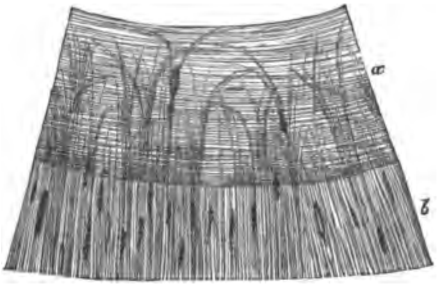

FIG. 150.—SEGMENT OF THE IRIS SEEN FROM THE POSTERIOR SURFACE AFTER REMOVAL OF THE UVEAL PIGMENT. (Iwanoff.)

a, sphincter muscle; *b*, dilatator muscle of the pupil.

The **muscular tissue of the iris** is disposed as a ring (*sphincter pupillæ*) around the pupil, and as rays (*dilatator pupillæ*) from the sphincter to the circumference.

The *sphincter* muscle (figs. 149, *s*, and 150, *a*) is a narrow band about 0·5 mm. wide, situated close to the pupil posteriorly and consisting of a number of bundles of plain muscular tissue running concentrically with the margin of the pupil. Here the bundles are closely arranged; but farther from the margin they are more separated, and form less complete rings.

The *dilatator* (figs. 149, *d*; 150, *b*; and 151, *d*), less apparent than the sphincter, begins at the ciliary or outer margin of the iris, and its fibres, converging towards the pupil, form a continuous membrane close to the posterior surface. This membrane has long been recognised, and was known as the *membrane of Bruch*, having been supposed to correspond with the similar membrane on the inner surface of the choroid. But it is undoubtedly composed of fibres having the histological character of plain muscle-cells, and with a general radial disposition. Towards the pupillary edge the fibres bend round and blend with the sphincter, some reaching nearly to its inner margin. Near its origin at the ciliary margin, the layer is somewhat thickened, the cells being here two or three deep (fig. 151). At the extreme periphery the fibres arch round and take a somewhat circular direction.

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[1] On the structure of the iris-stroma, see G. Retzius, Biol. Unters. v. 1893.

Many investigators have failed to find evidence of the existence of a distinct layer of dilator fibres, and have consequently denied its existence in man and mammals generally, whilst admitting it to be well developed in birds (where, as well as the equally well developed sphincter, it is of the striped variety) and in certain mammals, such as the otter. Other writers have strenuously contended for the existence of a dilator muscle. There is in fact unmistakable histological evidence of the presence of a thin layer of fibres at the back of the human iris, under the pigment-cells, having all the appearance of, and staining similarly to, plain muscle-cells.[1] Physiological proof of the existence of dilator fibres was furnished in the rabbit by Kölliker and in certain other animals by Langley and Anderson.

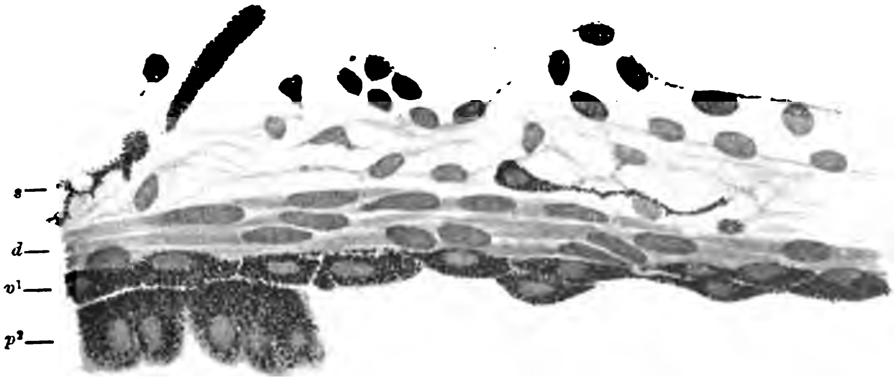

FIG. 151.—SECTION OF POSTERIOR LAYERS OF IRIS, HUMAN, NEAR ITS ATTACHMENT TO THE CHOROID. $\frac{200}{1}$. (E. A. Schäfer.)

s, iris stroma with connective tissue, branched pigment-cells, and blood-vessels; *d*, layer of dilatator pupillæ; *p*¹, deeper layer of flattened pigment-cells appearing spindle-shaped in section; *p*², superficial layer of pigment-cells of columnar shape. These cells are broken away from the layer part of the section.

In most animals the contraction and dilatation of the pupil are brought about reflexly. In the frog and eel the iris musculature is directly influenced by light. This is even the case with separated portions of the tissue.[2]

Vessels of the iris (figs. 145, 146, and 152).—The *long ciliary arteries*, two in number, pierce the sclerotic a little in advance and one on each side of the optic nerve. Having gained the interval between the sclerotic and choroid coats, they extend horizontally forwards covered by loose connective tissue to the ciliary muscle. In this course they lie nearly in the horizontal plane of the axis of the eyeball, the outer vessel being a little above and the inner one a little below the level of that line. Just behind the attached margin of the iris, each vessel divides into an upper and a lower branch, and these, anastomosing with the corresponding vessels on the opposite side and with the anterior ciliary, form a vascular ring (*circulus major*, fig. 145, *p*; fig. 155) in this situation. From this circle small branches arise to assist in supplying the ciliary muscle; while others converge towards the pupil (fig. 152), and there, freely communicating by transverse offsets from one to another, form a second circle of anastomosis (*circulus minor*), from which capillaries are continued inwardly and end in small veins. The arteries and veins of the iris have, relatively to their size, thick coats; they pursue a somewhat tortuous sub-parallel course. The capillaries of the iris are most numerous near the attached margin and in the neighbourhood of the sphincter pupillæ; the network is more open throughout its substance. The veins end in those of the ciliary processes. Both arteries and veins tend to run in small bundles or pencils. The veins freely anastomose.

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[1] See especially Merkel (Ergebn. der Anat. iii. 1893), H. E. Juler, in Trans. Eighth Intern. Ophth. Congress, 1894; and G. Retzius (Biol. Unters. v. 1893). Recent papers by Vialleton (Arch. d'Anat. micr. i. 1897), Grynfeltt ('Le muscle dilatateur,' 1899), Heerfordt (Anat. Hefte, Bd. 14, 1900), Hotta (Arch. f. Ophth. Bd. 62, 1905–6), Levinsohn (*ibid.*), and Nakaizumi (Tokio-Iji-Schinski, 1907, quoted from Schwalbe's Jahrb.) point to a similar conclusion; but while most of these last-named authors describe the muscular layer as a part of the deeper stratum of the uveal epithelium, Levinsohn and Nakaizumi, agreeing with Merkel, Retzius, and Juler, make it a distinct structure. There is no doubt that this last view, which was also that taken in the last edition of this work, is correct. The relations are particularly well seen near the periphery (Schäfer, Quart. Journ. Exp. Physiol. 1909). The dilatator, as well as the sphincter pupillæ, appears to be developed at the cost of the pars iridica retinalis (M. Nussbaum, Graefe-Saemisch, Handb. d. ges. Augenheilk., 2nd. ed., 1899; Heerfordt, *op. cit.*; Szili, Anat. Anz. xx. 1902; Jaselius, Finska läk handl. xliv. 1907).

[2] Steinach, Pflüger's Arch. Bd. lii.; Guth, Pflüger's Arch. Bd. lxxxv.

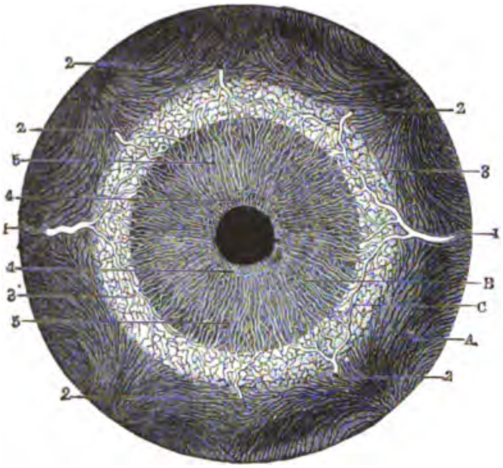

Fig. 152.—Front view of the blood-vessels of the choroid coat and iris from before. Magnified 2½ times. (Arnold.)

A, choroid; B, iris; C, ciliary muscle; 1, 1, long ciliary arteries; 2, 2, five of the anterior ciliary arteries ramifying at the outer margin of the iris; 3, loop of communication between one of the anterior and one of the long ciliary arteries; 4, internal circle and network of the vessels of the iris; 5, external radial network of vessels.

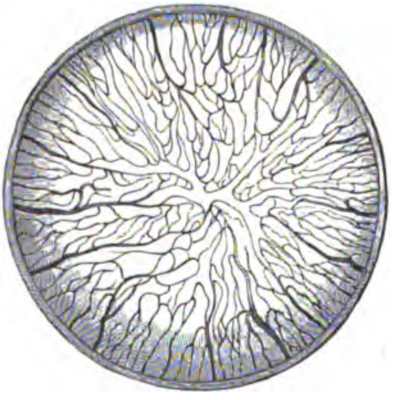

Fig. 153.—Pupillary membrane of new-born kitten, injected. Magnified. (Kölliker, from a preparation by Thiersch.)

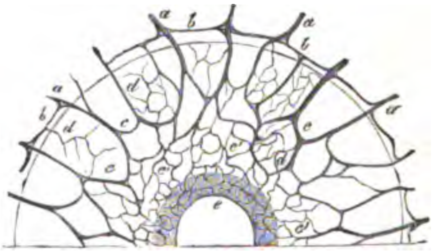

Fig. 154.—Distribution of nerves in the iris. 50 diameters. (Kölliker.)

The preparation was from the eye of an albino rabbit. *a*, smaller branches of the ciliary nerves advancing from the choroid; *b*, loops of union between them at the ciliary margin of the iris; *c*, arches of union in the iris; *c'*, finer plexus in the inner part; *e*, sphincter pupillæ muscle.

The *anterior ciliary arteries* (fig. 152, 2, 2; fig. 155), five or six in number, but smaller than the vessels just described, are supplied from the muscular and lacrymal branches of the ophthalmic artery, and pierce the sclerotic about 2 mm.

behind the margin of the cornea; they divide into branches which supply the ciliary processes, and join the circulus major.

Besides these special arteries, numerous minute vessels enter the iris from the ciliary processes.

The *veins* of the iris closely follow the arrangement of the arteries just described. The canal of Schlemm communicates with this system of vessels.

Pupillary membrane.—In the fœtus the pupil is closed by a thin transparent vascular membrane, the vessels in which are continued from those of the iris and of the capsule of the lens (which is also vascular in the fœtus). Near the middle of the pupil the vessels of the membrane loop round, leaving the centre free from vessels. They disappear in the seventh or eighth month of fœtal life, becoming obliterated from the centre towards the circumference, and the membrane itself is gradually absorbed. A few shreds may still remain at birth; sometimes the whole membrane persists.

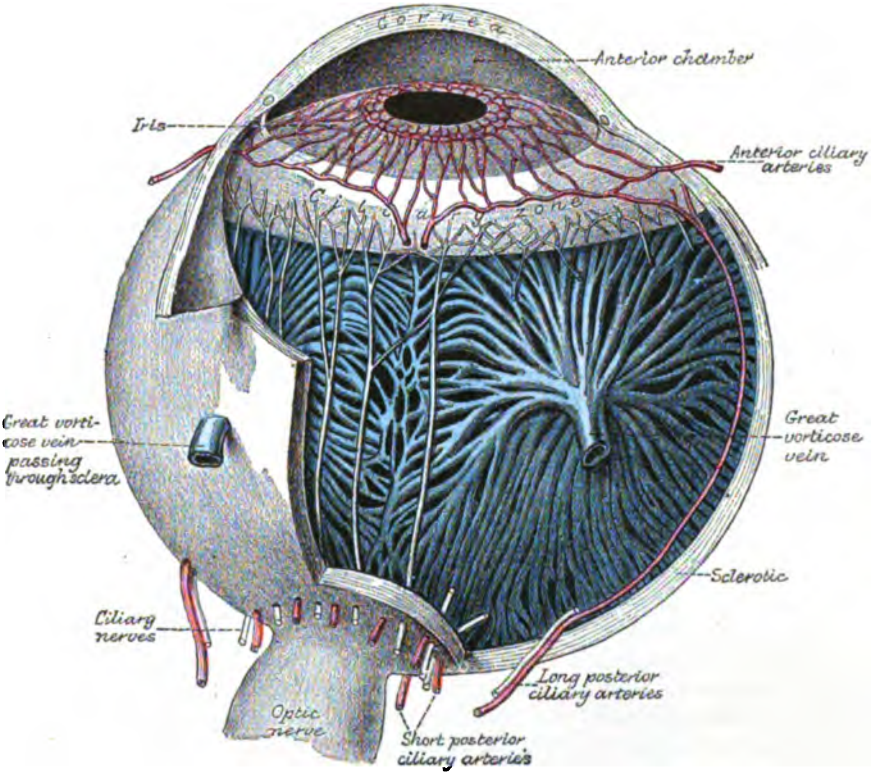
Cornea
Anterior chamber
Iris
Anterior ciliary arteries
Ciliary zone
Great vorticose vein passing through sclera
Great vorticose vein
Sclerotic
Ciliary nerves
Long posterior ciliary arteries
Optic nerve
Short posterior ciliary arteries

FIG. 155.—DIAGRAM SHOWING THE PRINCIPAL NERVES AND BLOOD-VESSELS OF THE EYEBALL. (Testut.)

Nerves of the choroid and iris.—The *ciliary nerves* (figs. 135, 155), about fifteen in number, derived from the ciliary ganglion and the nasal branch of the ophthalmic division of the fifth nerve,[1] pierce the sclerotic near the entrance of the optic nerve, and come immediately into contact with the choroid. They are somewhat flattened in form, are partly imbedded in grooves on the inner surface of the sclerotic, and communicate occasionally with each other before supplying the cornea and entering the ciliary muscle. When the sclerotic is carefully separated from the subjacent structures, these nerves are seen lying on the surface of the choroid, into which they send branches, and in which they form a gangliated plexus among the blood-vessels, the groups of ganglion-cells being often applied to the walls of the vessels. Within the ciliary muscle the nerves also subdivide minutely, forming here another plexus, which still contains a number of medullated fibres; the ganglion-cells of this plexus are smaller. A few recurrent branches appear to pass back from it into the choroid coat, but the greater number pass on to the iris (fig. 154, *a*, *a*). In the iris the nerves follow the course of the blood-vessels, dividing into branches, which communicate with one another as far as the pupil, forming a close plexus of fine non-medullated fibres. Their ultimate destination is mainly the muscular tissue of the iris and of its vessels.[1] The nerves of the ciliary body are mainly destined for the ciliary muscle, but some go to the blood-vessels, and there are also others which from their mode of termination are believed to be sensory, running both over and within the ciliary muscle.[2]

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[1] The origin and connexions of the ciliary nerves has been worked out in minute detail in the rabbit by M. Peschel (Arch. f. Ophth. xxxix. 1893).

THE OPTIC NERVE AND RETINA (TUNICA NERVOSA).

STRUCTURE OF THE OPTIC NERVE.

The optic nerve differs in structure from all other cerebrospinal nerves. It is not composed of round funiculi of nerve-fibres, but its section is divided up by a network of coarser and finer fibrous septa (primary and secondary septa of Leber) into a great number of compartments or meshes, of an angular or rounded angular shape and variable size. These are occupied by the nerve-bundles, which take the shape of the compartments, and by neuroglia-cells, similar to those of the nerve-centres, which lie between the fibres. There are about 800 of these bundles in man. The individual nerve-fibres, which are all medullated, vary in diameter from 1 μ to 10 μ, but only a few are of the largest diameter, most being about 2 μ or 4 μ in size. As Gudden first showed, the great majority of the optic nerve-fibres are of two sizes, larger and smaller. In some animals, such as the cat, the two kinds are nearly equal in number. They probably subserve different functions. The nerve-fibres have no neurolemma, and are therefore not easily isolated in teased preparations. It is computed that there are in all about 400,000 fibres in the nerve (Krause). As in the white matter of the nerve-centres, it is not uncommon to find corpora amylacea (see Part I. of this volume, p. 76) in the optic nerve.

The section of the whole nerve is nearly circular, and in man measures about 3 mm. in diameter. It is surrounded by three sheaths, viz.: 1. The *dura-sheath*, a very thick fibrous sheath derived from the dura mater and continuous with the scleral coat of the eyeball. 2. A delicate sheath lying like an enclosing curtain in a well-marked lymph-space, which is bridged across here and there by offsets from the membrane. This is the *arachnoid-sheath*. The part of the lymph-space which lies between it and the dura-sheath is continuous with the subdural space of the brain; that which lies between the arachnoid- and pia-sheaths is continuous with the subarachnoid space of the brain. 3. A vascular *pia-sheath*, continuous with the pia mater of the brain, and connected on its inner surface with the septa which serve to subdivide the nerve into compartments. But in many places, as is also the case in the spinal cord, the nerve-fibres do not abut closely against the pia-sheath, but are separated from it by a stratum of neuroglia. Immediately internal to this glial stratum, where it occurs, the septal trabeculæ have a tendency to run parallel with the pia-sheath (Fuchs). Blood-vessels pass into the nerve from the pia-sheath, along the interlacing septa.

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[1] For nerve-endings in iris, see Meyer, Arch. f. mikr. Anat. xvii. 1880; Hosch, Arch. f. Ophth. xxxvii. 1891; G. Retzius, Biol.-Unters. v. 1893.

[2] Agagabow and Arnstein, Anat. Anz. viii. 1893; Agagabow, Int. Monatsch. f. Anat. u. Phys. Bd. xiv.

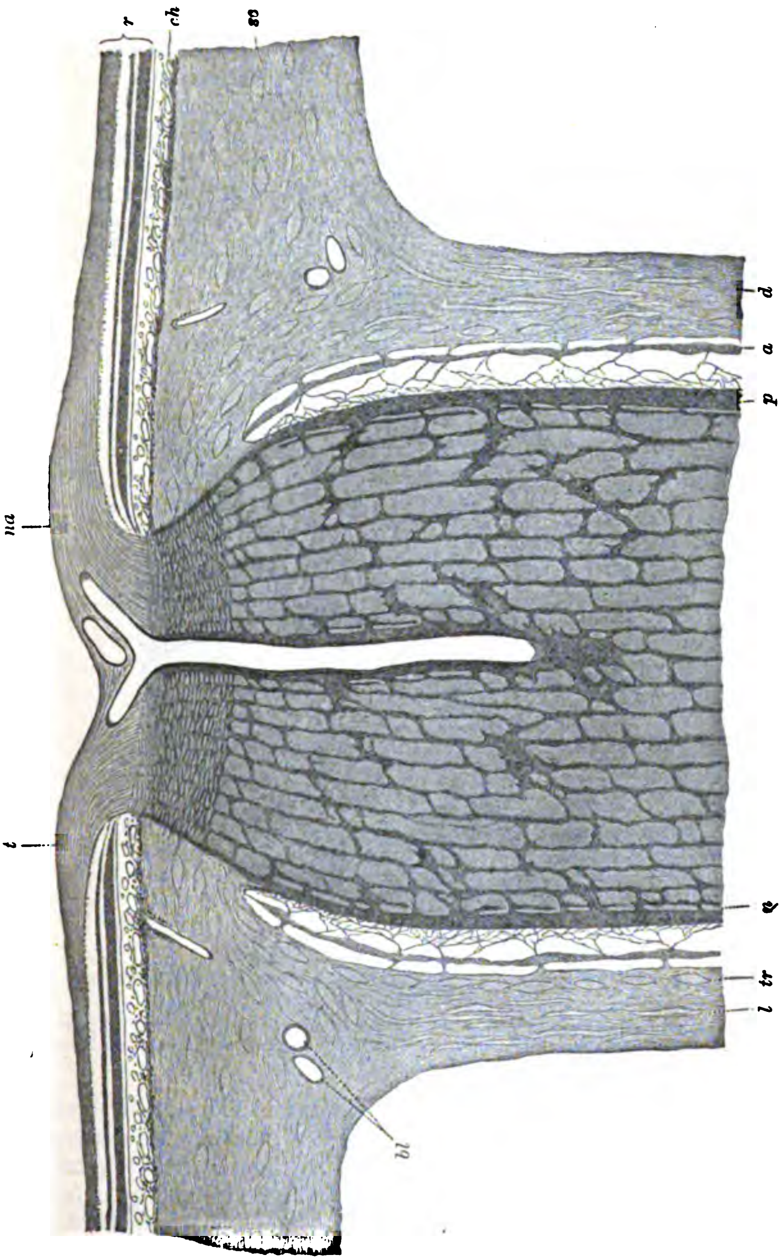

FIG. 156.—LONGITUDINAL SECTION THROUGH THE OPTIC NERVE AT ITS ENTRANCE INTO THE EYEBALL. Diagrammatic. Magnified about 24 times. (Greeff.)

d, dura-sheath; *a*, arachnoid-sheath; *p*, pia-sheath (on either side of *a*, a lymph-space which ends blindly at the inner third of the thickness of the sclera); *sc*, sclera; *ch*, choroid; *r*, retina; *n*, *t*, nerve-fibre layer forming a prominence at the edge of the disc, rather more marked on the nasal side (*n*) than on the temporal (*t*); *bl*, blood-vessels belonging to a vascular ring in the sclera; *n*, surface-layer of neuroglia on optic nerve; *tr*, transverse bundles in sclera; *l*, lymph-clefts in sclera. The optic nerve itself is subdivided by longitudinal and transverse septa; near its anterior extremity these become very closely set and form the lamina cribrosa. The middle of the nerve is occupied by the central vessels, one of which is in part cut longitudinally.

The septa of the nerve contain, as do also the sheaths, many elastic fibres (Sattler). These are especially numerous near the point of entrance of the nerve into the globe, especially at the *lamina cribrosa*.

The septal structure of the optic nerve begins at the passage of the nerve out from the chiasma. This last and the optic tracts are in man and mammals covered, like the rest of the brain, with a comparatively loose layer of pia mater, giving off only delicate prolongations internally; whereas, as we have seen, the pia-sheath of the optic nerve itself is intimately connected by the septa above described with the interior of the nerve. The septa are, on the whole, thinner and less frequent in the anterior than in the posterior part of the nerve, but they become considerably more marked again after the entrance of the central vessels, and are especially well developed at the lamina cribrosa. The appearance of the section of different parts of the nerve is modified by the presence or absence of the central retinal artery or vein. These vessels generally enter the nerve on the under-side, a few millimetres from the globe, and are therefore seen lying side by side in sections of the most anterior part of the nerve, occupying the centre of the circle formed by the outline of the section (figs. 157, 158). They are surrounded by fibrous and elastic tissue, and are accompanied by small parallel-running branches. At their entry they are enclosed within a considerable trabecula of fibrous tissue, continuous with the pia-sheath, and extending to the middle of the nerve. Behind this point, the centre of the nerve, nearly as far as the foramen opticum, is occupied by the sections of a recurrent branch of the central artery and of an accompanying venous twig (Vossius), which gradually lose themselves in terminal ramifications within the nerve. In the region of the optic foramen the centre is again occupied by a small vein (Kuhnt) of about the same diameter as the central retinal vein. This vein—the *vena centralis posterior*—belongs to the nerve itself, collecting blood from the capillaries of the orbital part of the nerve; it emerges from the nerve on its under-surface and passes outwards to join the cavernous sinus. The branches of the central vessels

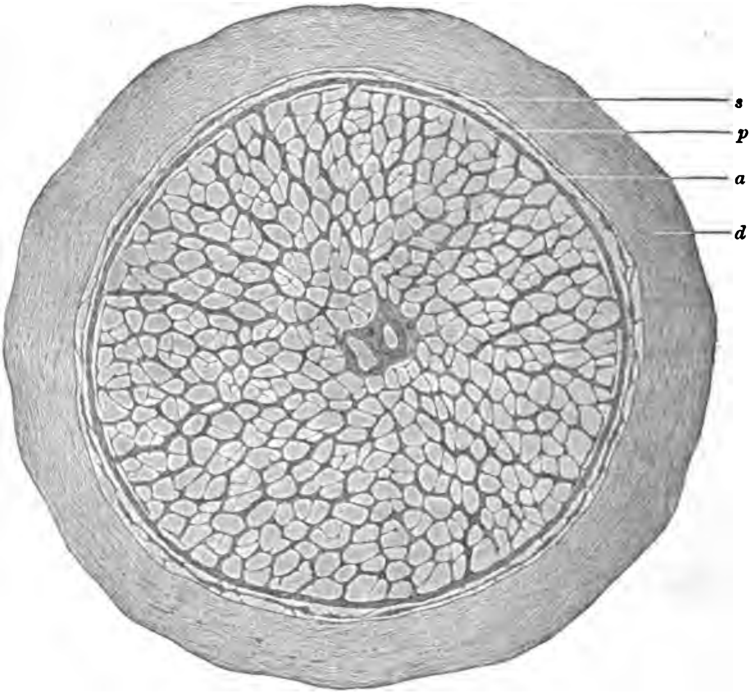

FIG. 157.—SECTION OF THE OPTIC NERVE A FEW MILLIMETRES BEHIND ITS ENTRANCE INTO THE EYEBALL. Magnified about 24 diameters. (Greeff.)

d, dura-sheath; *a*, arachnoid-sheath; *p*, pia-sheath; *s*, septa between the nerve-bundles (the line points to one of the septal trabeculæ which is concentric with the pia-sheath and is separated from it by neuroglia-tissue).

in the neighbourhood of the lamina cribrosa communicate with branches of the posterior ciliary arteries distributed to the sclera, and also with the choroidal vessels (figs. 160 and 161).

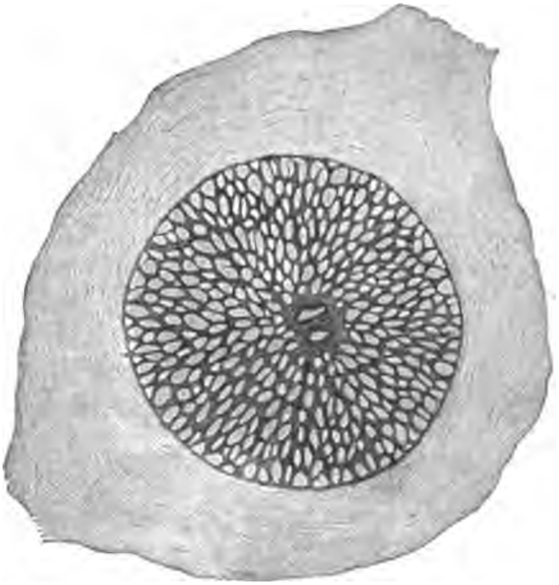

FIG. 158.—SECTION OF THE OPTIC NERVE IN THE REGION OF THE LAMINA CRIBROSA. Magnified about 24 diameters. (Greeff.)

Various observers have described nerve-fibres, mainly non-medullated, as accompanying the central artery and vein, and Westphal believes that other fibres, derived from the ciliary nerves, run in the septa and between the optic fibres proper. But the matter is one which requires renewed investigation by modern methods.

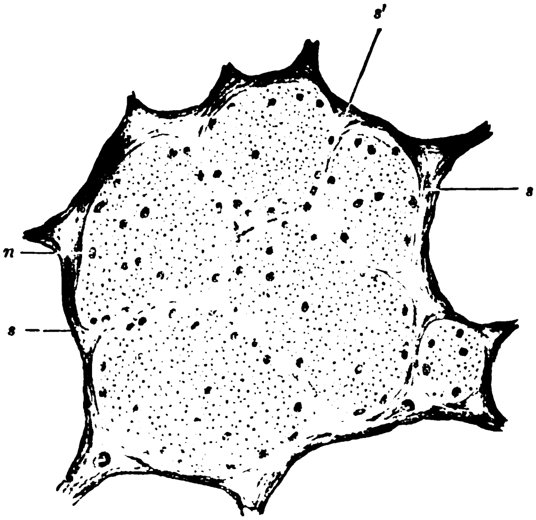

FIG. 159.—SECTION THROUGH ONE OF THE LARGER BUNDLES OF THE OPTIC NERVE. Magnified 240 diameters. (Greeff.)

s, *s*, primary septa, which separate the larger bundles; *s′*, a secondary septum, between the smaller bundles; *n*, nucleus of a neuroglia-cell.

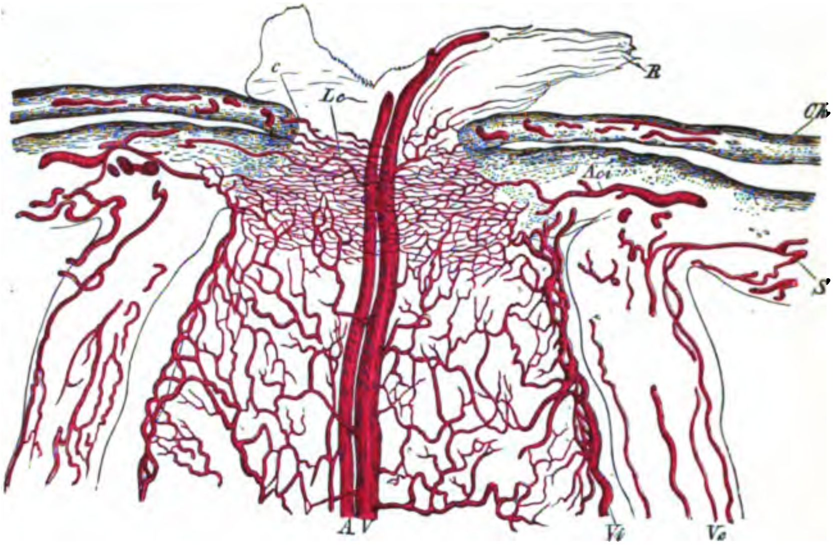

FIG. 160.—LONGITUDINAL SECTION THROUGH THE ENTRANCE OF THE OPTIC NERVE INTO THE EYEBALL. (Leber.)

The specimen was injected from the ophthalmic artery; the injection of the retinal branches is incomplete.

S, sclera; *Ch*, choroid; *R*, retina; *Ve*, vessels of dura-sheath of nerve; *Vi*, vessels of pia-sheath; *A*, central artery; *V*, central vein; *Lc*, lamina cribrosa; *Aci*, branch of short posterior ciliary arteries passing to optic nerve; *c*, vessels passing between choroid and optic nerve.

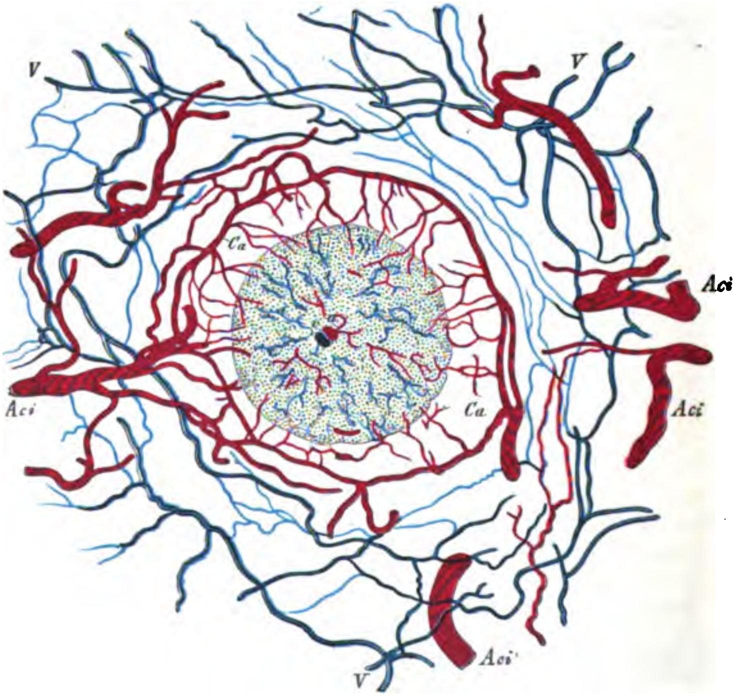

FIG. 161.—CIRCULUS ARTERIOSUS NERVI OPTICI. (Leber.)

Aci, posterior (short) ciliary arteries; *V*, posterior (short) ciliary veins; *Ca*, arterial circle round the optic nerve (this circle lies in the sclera, which is not represented); *a*, central artery; *v*, central vein, in middle of optic nerve.

Lymph-spaces of the optic nerve.—The spaces which lie between the dura- and pia-sheaths of the nerve are lined with endothelium and are continued behind into, and can be injected from, the corresponding spaces of the brain. If this communication is cut off by a ligature, and coloured injection-fluid is passed by means of a hypodermic syringe into the spaces around the nerve, the fluid is found after a time to penetrate into clefts in its interior, passing between the fibrous septa and the nerve-bundles and extending forwards even beyond the lamina cribrosa, but not passing beyond the limits of the optic disc. On the other hand, the spaces themselves stop abruptly at the place where the nerve begins to pass through the sclerotic. But Michel was able to inject the peri-choroidal space within the globe from the peri-optic space, through lymph-clefts in the sclerotic. There is also a supra-dural lymph-space outside the dura-sheath, communicating anteriorly with the capsule of Tenon.[1]

THE RETINA.

The retina is a delicate membrane which contains the expanded termination of the optic nerve. It lies within the choroid coat, and rests on the hyaloid membrane of the vitreous humour. It extends forwards nearly to the outer edge of the ciliary processes of the choroid, where it ends abruptly in an indented border, named *ora serrata*. From this border there is continued onwards a thin layer of a different structure and containing no nerve-fibres, the *pars ciliaris retinæ*, which reaches as far as the tips of the ciliary processes, and there gives place to the double layer of pigment known as the *uvea*, which is continued on to the posterior surface of the iris (*pars iridica retinæ*). The thickness of the retina diminishes from behind forwards, from 0·4 mm. near the yellow spot to about half that thickness at the equator and one-fourth at the ora serrata. In the fresh eye it is translucent and of a light pink colour, but of a purple-red colour if kept in the dark for a little while before removal. Under the influence of sunlight this colour is quickly bleached, and after death the retina soon becomes opaque. The colouring-matter was discovered by Boll; it was specially investigated by Kühne, who gave it the name of *rhodopsin*. It is absent at the yellow spot (and central fovea), and also close to the ora serrata. The outer surface of the retina is covered with a layer of hexagonal pigment-cells which send fine offsets between the elements of the next retinal layer (rods and cones): the rhodopsin becomes developed in the rods by the agency of these pigment-cells. When the choroid is detached the offsets are ruptured and most of the pigment-layer comes away with it, so that this layer was formerly described as part of the choroid coat.

The inner surface of the retina is smooth: on it the following objects may be seen. Nearly in the axis of the ball is a yellow spot—*macula lutea* (*limbus luteus*, Sömmerring)—which is somewhat elliptical in shape and about 2 mm. in diameter: in the centre of this, again, is a slight hollow, *fovea centralis*, usually stated to be from 0·2 mm. to 0·4 mm. in diameter, but in some cases certainly measuring at least 1 mm.,[2] and, as the retina is thinner here than elsewhere (about ·1 mm.), the pigmentary layer is more clearly visible through it in the dead condition, giving rise to an appearance as of a hole through the tunic. About 3 mm. inside the yellow spot and about 1 mm. below the level of a horizontal line through the posterior pole of the eyeball is a whitish circular patch, the *optic disc* or *porus opticus* (fig. 162 and Plate), where the optic nerve pierces the retina and expands to form its inner layer. The circumference of the disc is slightly elevated to form an eminence (*colliculus seu pupilla nervi optici*) (fig. 156), and in its centre, which often shows a well-marked depression, the so-called *physiological excavation*, is the point from which the vessels of the retina branch. The disc is about 1·5 mm. in diameter. It is bounded by a dark ring which represents the edge of the choroid. Within this is a thin white circle, the scleral ring.

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[1] These lymph-spaces of the optic nerve were originally investigated by Schwalbe (Arch. f. mikr. Anat. Bd. vi. 1869; Sächs. Berichte, 1872), by Key and Retzius (Nord. Med. Arkiv, 1870, and Studien in der Anatomie des Nervensystems, 1875), and by Michel (Archiv f. Heilkunde, 1872). Subsequent observers have added little to their descriptions.

[2] Golding Bird and Schäfer (Int. Monatsch. f. Anat. u. Phys. 1895). According to Dimmer (Arch. f. Ophth. Bd. 65, 1907), the fovea is as wide as 1·5 mm., forming a shallow depression, and the yellow colour of the macula is confined to its central third, so that, contrary to the generally received description, the macula lutea is in the middle of the fovea. The statement of Gullstrand (Arch. f. Ophth. Bd. 62, 1905), that the yellow colour is merely a post-mortem appearance, seems to be quite unfounded. The colour is very persistent after death (Schmidt-Rimpler, Arch. f. Ophth. 1904).

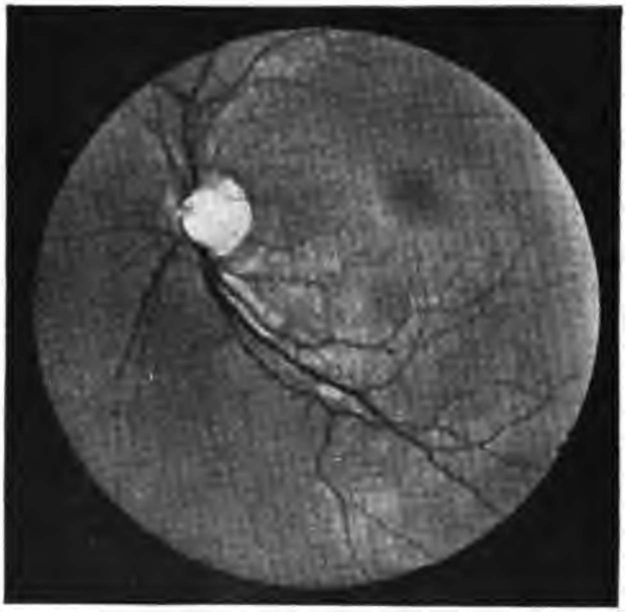

FIG. 162.—FUNDUS OF HUMAN EYE. Magnified about 8 diameters. (From a photograph by Dimmer.) The optic disc is seen on the left with the branches of the central vessels emerging from it. The shaded patch to the right is the macula and fovea.

When examined during life by the aid of the ophthalmoscope, the optic disc appears of a light grey tint, contrasting strongly with the red colour of the rest of the field (see Plate). In the central depression of the disc are remnants of the tissue which, in the fœtus, accompanied the prolongation of the central artery of the retina along the canal of Stilling (p. 254) through the vitreous body to the capsule of the lens; in some eyes this tissue can be followed for some distance into the vitreous humour.[1]

MICROSCOPIC STRUCTURE OF THE RETINA.[2]

When vertical sections of the retina—*i.e.* sections made perpendicularly to its surface—are submitted to microscopic examination, eight distinct strata are recognisable, together with certain fibrous structures which pass vertically through the membrane and connect the several layers.

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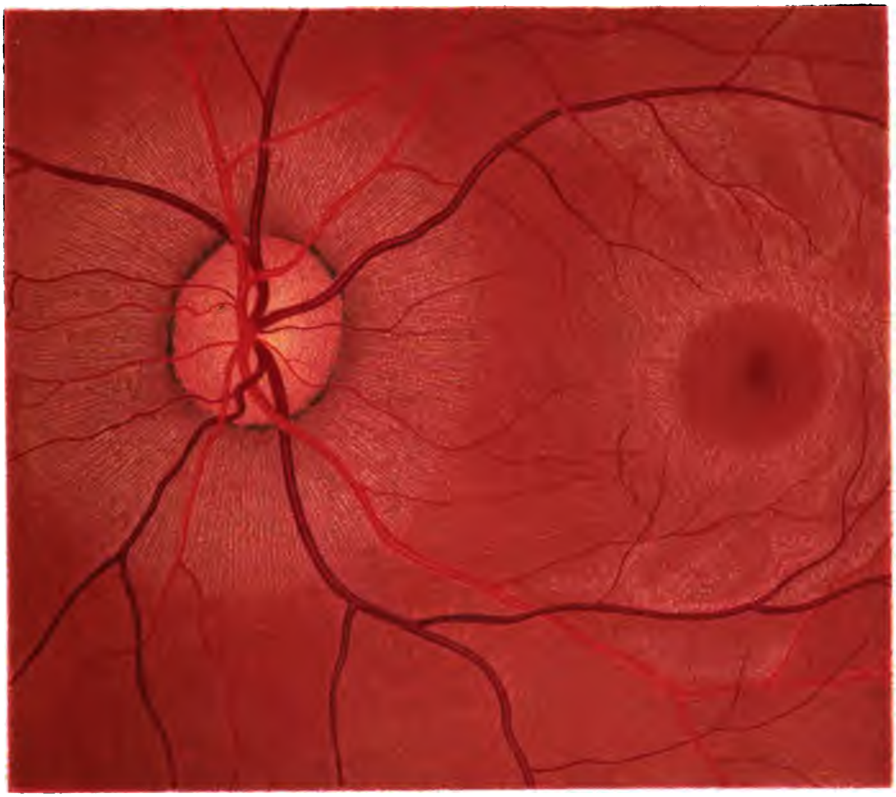
[1] For the appearances of the disc in man and mammals, see Lindsay Johnson, Phil. Trans. B. vol. 194. On the structure of the optic nerve at its entrance into the retina, see Elschnig, Denkschr. d. Wiener Akad. Bd. lxx. For an account of the general course of the optic fibres as they may be observed in surface preparations made from the bichromate-fixed retina, see Michel, Ludwig-Festschrift, 1875.

[2] For the literature of this subject up to 1899, the article by Greeff in Graefe-Saemisch, Handb. d gesamt. Augenheilkunde (2nd ed.), may be consulted.



Fundus oculi of a dark-haired English woman aged 20, as seen with the ophthalmoscope (G. Lindsay Johnson). Magnified about 15 diameters.

On the left is the optic disc, encircled by the choroid ring and with the branches of the central artery and vein emerging from its centre. The striations radiating from the circumference of the disc are caused by reflexion of light from the fibre-bundles in the optic nerve-layer. The darker nearly circular patch on the right is the macula. It is surrounded by a brighter zone caused by light-reflexion. The fovea appears as a somewhat more deeply coloured area at its centre.

MU

The following are the designations of the layers, from within outwards (fig. 163):

1. The layer of nerve-fibres (*stratum opticum*).
2. The layer of nerve-cells (*ganglion nervi optici*).
3. The inner plexiform or molecular layer (*stratum reticulare internum*).
4. The inner nuclear layer (layer of bipolar cells) (*stratum granularum internum, ganglion retinæ*).
5. The outer plexiform or molecular layer (*stratum reticulare externum*).
6. The outer nuclear layer (layer of rod- and cone-nuclei) (*stratum granularum externum*).
7. The layer of rods and cones (*stratum bacillorum*).
8. The layer of hexagonal pigment-cells (*stratum nigrum*).

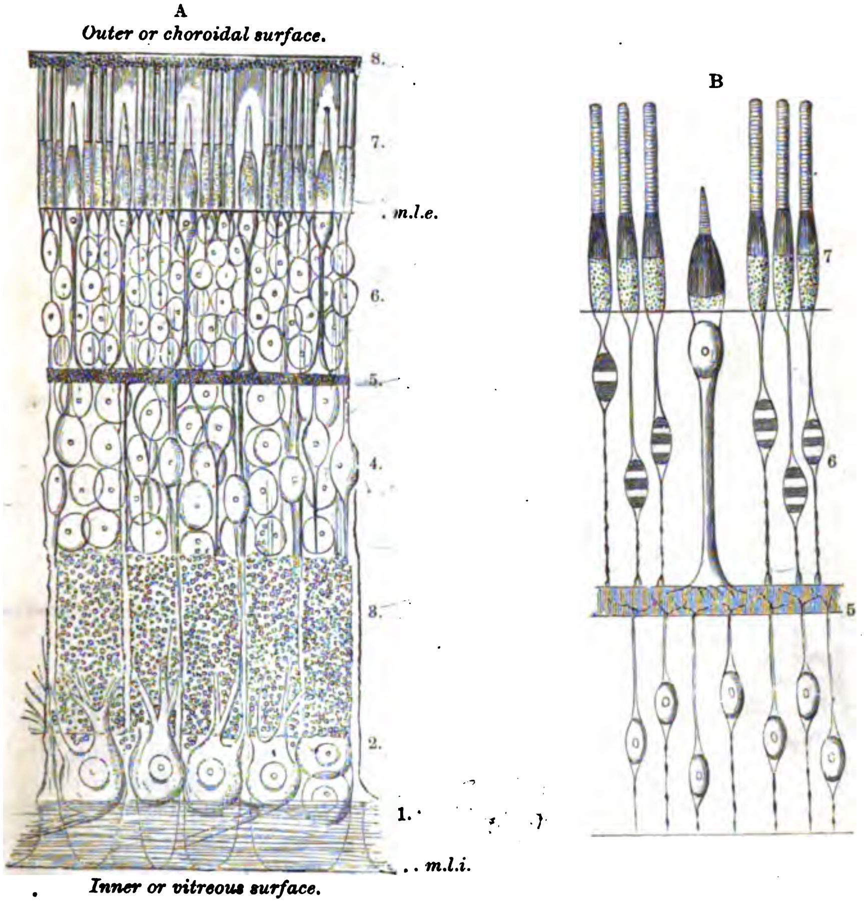


FIG. 163.—A. DIAGRAMMATIC SECTION OF THE HUMAN RETINA. (Schultze.) B. DIAGRAM OF THE ROD- AND CONE-ELEMENTS AND BIPOLARS. (Schwalbe.)

In addition to these eight strata, two delicate membranes have been described—the one, *membrana limitans interna, m.l.i.*, bounding the retina on its inner surface, next to the hyaloid membrane of the vitreous humour; the other, *membrana limitans externa, m.l.e.*, lying between the outer nuclear layer and the layer of rods and cones; but, as will be afterwards explained, these so-called 'membranes' are merely the boundary-lines of the sustentacular tissue of the retina.

The several layers of the retina will first be considered successively as they are met with from within out, after which the sustentacular fibres or fibres of Müller, which traverse several of the layers, and the connexion of the nervous elements throughout the retina with one another will be described. Finally, an account will be given of those parts of the retina which present points of difference from the rest, especially the central fovea, and the ciliary part.

1. **Layer of nerve-fibres.**—The optic nerve passes at the porus opticus directly through the thickness of the retina to reach its inner surface (fig. 156), on which it spreads out in the form of a membrane, thickest at the optic disc, which extends, gradually becoming thinner, to the ora serrata. In its passage it, as it were, cuts through the retinal layers somewhat obliquely, so that the rod- and cone- and pigment-layers project farther inwards towards the centre of the papilla than the rest. The nerve-fibres, which are throughout destitute of neurolemma, lose their medullary sheath as they pass through the lamina cribrosa, so that they have no medullary sheaths within the retina, consisting there normally of axis-cylinder only (Bowman). In rare cases in man some of them may retain their medullary sheath for a short distance. Such streaks of medullated fibres are constantly found in the rabbit and hare on either side of the papilla. The nerve-fibres are collected into small bundles, which, compressed laterally, intercommunicate and form a delicate web with narrow elongated meshes (fig. 164). At the yellow spot this layer is almost wanting, and indeed it ceases at the central fovea, but elsewhere it forms a continuous stratum, gradually diminishing in thickness in front, interrupted only by the enlarged ends of the fibres of Müller to be afterwards described (p. 243). Most of the fibres are continuous with the axis-cylinder processes of the cells of the next layer (fig. 165, I.), but some are continued through the second and third layers and end by ramifying either in the inner molecular layer or among the elements of the fourth layer (inner granules), the terminations being frequently somewhat knobbed or enlarged (fig. 165, I. *m*). These are to be regarded as fibres which originate in the brain or in the opposite retina.[1] Besides the endings of the Müllerian fibres, the optic-fibre layer also

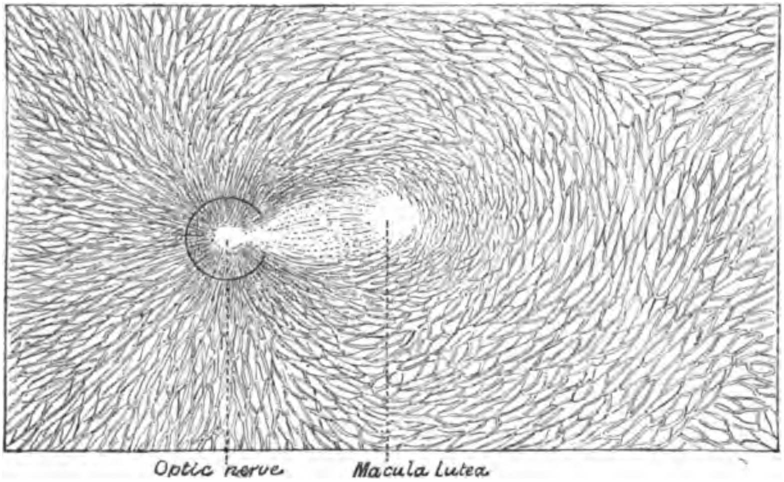


FIG. 164.—MAGNIFIED VIEW OF THE INNERMOST LAYER OF THE RETINA, SHOWING THE BUNDLES OF OPTIC NERVE-FIBRES RADIATING FROM THE PAPILLA. (Merkel.)

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[1] Parsons found degenerated fibres in the opposite optic nerve as the result of retinal lesions produced experimentally in one eye of the monkey (Proc. Physiol. Soc., Journ. Physiol. xxiii.).

contains stellate neuroglia-cells, some of which are attached to the membrana limitans interna.

Marengli[1] has described collaterals from the optic nerve-fibres passing into the ganglionic layer and there forming plexuses. Cajal failed to find collaterals in birds and mammals, although admitting that they may occur exceptionally in reptiles.[2]

2. **Ganglionic layer.**—Immediately external to the nerve-fibre layer is a stratum of nerve-cells (fig. 163, 2), having in the fresh condition a pellucid aspect. The cells vary much in size and in figure, some being spheroidal, others more pyriform. Each cell has a single unbranched nerve-fibre process extending obliquely from its rounded inner extremity among the fibres of the preceding layer, with one of which it is continuous. From the opposite end of the cell, which is frequently imbedded in the substance of the succeeding layer, one, two, or more much thicker protoplasmic processes extend outwards for a variable distance into that stratum, and branch in its substance (fig. 165, v., vi., vii.). The branching occurs at different levels for different cells, the smaller cells as a rule having the terminal ramification of their protoplasmic processes nearer the ganglionic layer, the larger ones nearer the inner nuclear layer. The arborisations are mostly flattened conformably with the retinal strata, and in sections of retina produce the appearance of coarse lines in the molecular stratum. The number of nerve-cells and consequently the thickness of the ganglionic layer in the different regions of the retina varies largely. Over the greater part of the retina they form a single stratum, but in the neighbourhood of the yellow spot they are placed two or three deep. At the spot itself (fig. 177, 2) they are very thickly set; the cells are also smaller here. Towards the ora serrata, on the other hand, there is but a single stratum, and that frequently incomplete. The nerve-cells of this layer are provided with Nissl granules which vary in size with the volume of the cell-body,[3] and they also exhibit neuro-fibrils of the usual character.[4] Their granules undergo chromatolysis after section of the optic nerve[5] and also after prolonged exposure of the eyes to light (fatigue effect). This is also the case with the Nissl granules of the bipolars.[6] The nuclei of these cells also stain less deeply with basic dyes after prolonged exposure of the eye to light (G. Mann).

The ganglion-cells of the retina are classed by Cajal into those the protoplasmic or peripheral processes of which ramify in a diffuse manner in the inner molecular layer, and those the protoplasmic processes of which are ramified horizontally in one or more of the strata of that layer, where they interlace with similar ramifications from the cells of the inner nuclear layer. The diffusely ramifying cells (fig. 165, vii. *i*) are usually small and with slender processes, and this is also the case with some of the cells with stratified processes (fig. 165, v. *a*; vi. *e*), but many of the latter are larger, sometimes very large, and with comparatively coarse processes.

The cells with stratified processes are again classified by Cajal according to the stratum of the inner molecular layer in which these processes ramify. Some, however, ramify in two, and even in more layers (bi- and multi-stratified). Three types of the stratified cells can usually be distinguished. They may be termed, *first*, *second*, and *third*, or from their relative size, *large*, *medium*, and *small*, and some of each type appear to belong, as regards the distribution of their arborescence, to each stratum of the inner molecular layer.

First type.—Those of the large type have a thick axis-cylinder process and one, two, or more coarse protoplasmic processes, varying in vertical extent in different cells according to the stratum of the inner molecular layer for which they are destined. Their terminal arborescences extend over a considerable area, and are open in nature. The largest cells of this type (giant cells) send their processes to the outer strata of the molecular layer

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[1] Anat. Anz. xviii. Ergänzungsheft, 1900.

[2] La Cellule, 1892.

[3] Abeldort, Arch. f. Augenh. xlii.

[4] Embden, Arch. f. mikr. Anat. lvii.

[5] Birch-Hirschfeld, Arch. f. Ophth. l. 1890.

[6] Carlson (in cormorant), Amer. Journ. of Physiol. ii. 1903.

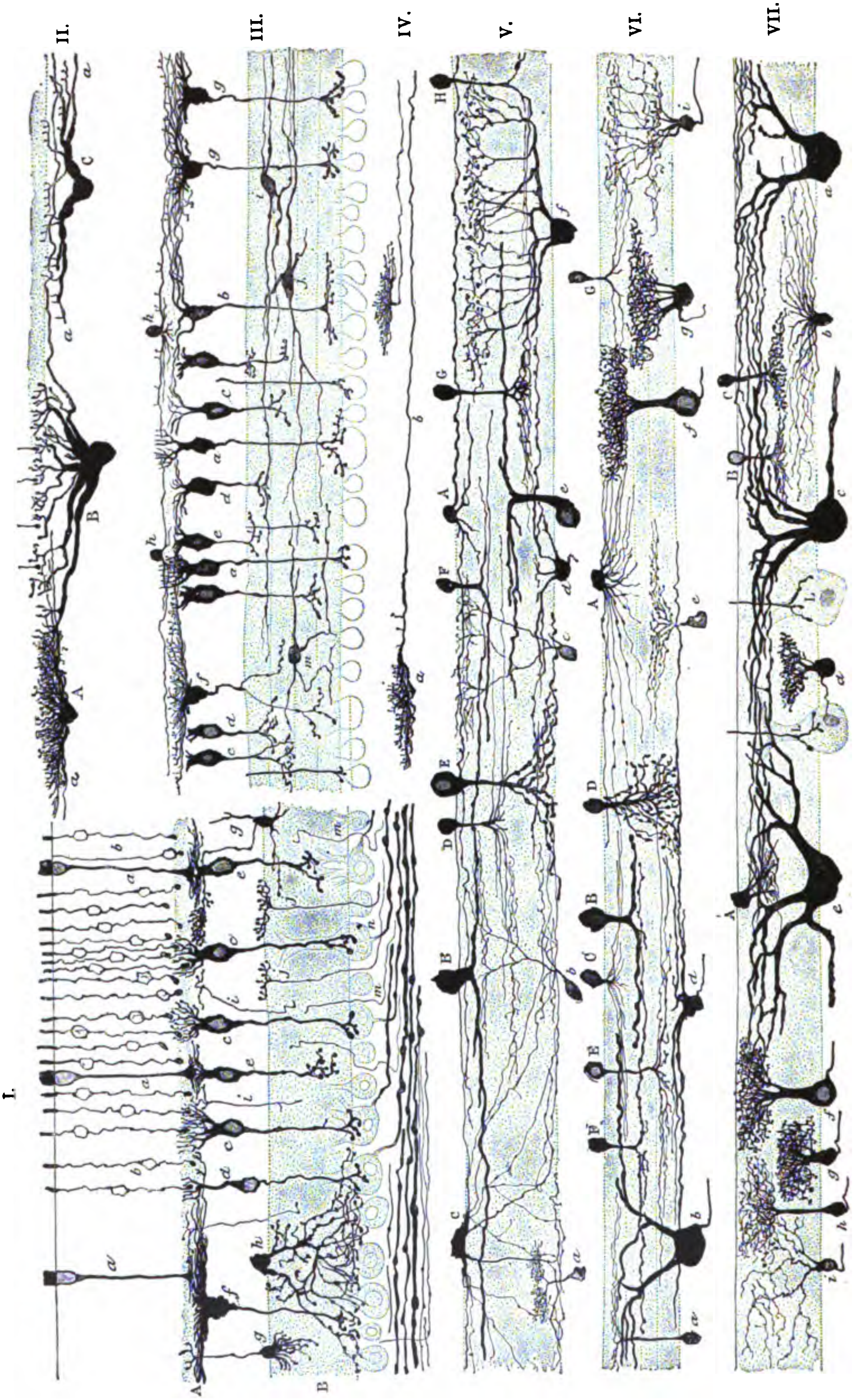
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FIG. 165.

(fig. 165, vii. *a*, *c*, *e*); processes to the inner strata come from cells of the same type but of smaller size.

Second type.—The ganglion-cells of this type (fig. 165, vi., vii. *f*, *g*, *h*) vary in size of cell-body, but are usually smaller than those of the first type, and of pyriform shape, the stalk of the pear being directed outwards for a variable distance in the molecular layer according to the position within this of the terminal arborescence. The latter is composed of moderately fine varicose filaments which form a compact, closely interwoven ramification, occupying some thickness of the molecular layer, the arborescence being less flattened out than is the case with those from many of the cells of the first and third types.

Third type.—This is represented by cells usually pyriform with small cell-bodies and correspondingly fine moderately arborescent processes, which may radiate from the end of a straight outwardly directed stalk, as in the case of those which ramify in the outer strata of the molecular layer (fig. 165, vi. *a*), or may spring in a similar radiating manner from the body of the cell itself, as with those ramifying in the inner strata (fig. 165, vii. *b*). A. Dogiel[1] described twin nerve-cells in the human retina as occasionally found, especially in the neighbourhood of the macula. In these there are two cell-bodies united by a comparatively thick strand of cytoplasm; only one of the two gives off an axon. They have also been seen by Greeff.[2]

3. **Inner molecular or inner plexiform layer, neurospongium.**—Next in order to the ganglionic layer comes a comparatively thick stratum of a granular-looking substance, which, as preparations treated by the methods of Ehrlich or of Golgi show, is mainly made up of the arborescent terminations of the processes of the cells in the layers which bound it internally and externally. A few branched cells, apparently of nervous nature, occur within the layer (fig. 165, iii.); these are probably allied to the amacrine cells of the layer next to be described. The interlaced arborisations of the ganglion-cells, amacrine cells, and bipolars form within it definite strata which, according to Cajal, are altogether five in number. There are a few blood-vessels in this layer,

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[1] Arch. f. Anat. 1893. For other observations by Dogiel, see Anat. Anz. iii. 1888, and Arch. f. mikr. Anat. xxxviii. 1892, xl. 1893, and xliv. 1895.

[2] Arch. f. Augenh. xxx. v. 1897.

FIG. 165.—ELEMENTS OF THE RETINA OF MAMMALS DISPLAYED BY THE SILVER-CHROMATE METHOD OF GOLGI. (Cajal.)

I. Section of the dog's retina. A outer molecular, B inner molecular layer. *a*, cone-fibre; *b*, rod-fibre and nucleus; *c*, *d*, bipolar cells (inner granules) with vertical ramification of outer processes destined to receive the enlarged ends of rod-fibres; *e*, bipolars with flattened ramification for ends of cone-fibres; *f*, giant bipolar with flattened ramification; *g*, cell sending its axon or nerve-fibre process to the outer molecular layer; *h*, amacrine cell with diffuse arborisation in inner molecular layer; *i*, nerve-fibrils passing to outer molecular layer; *j*, centrifugal fibres passing from nerve-fibre layer to inner molecular layer; *m*, nerve-fibril passing into inner molecular layer; *n*, ganglionic cells.

II. Horizontal or basal cells of the outer molecular layer of the dog's retina. A, small cell with dense arborisation; B, large cell, lying in inner nuclear layer, but with its processes branching in the outer molecular; *a*, its horizontal neuron; C, medium-sized cell of the same character.

III. Cells from the retina of the ox. *a*, rod-bipolars with vertical arborisation; *b*, *c*, *d*, *e*, cone-bipolars with horizontal ramification; *f*, *g*, bipolars with very extensive horizontal ramification of outer process; *h*, cells lying on the outer surface of the outer molecular layer, and ramifying within it; *i*, *j*, *m*, amacrine cells within the substance of the inner molecular layer.

IV. Axons or axis-cylinder processes belonging to horizontal cells of the outer molecular layer, one of them, *b*, ending in a close ramification at *a*.

V. Nervous elements connected with the inner molecular layer of the ox's retina. A, amacrine cell, with long processes ramifying in the outermost stratum; B, large amacrine with thick processes ramifying in second stratum; C, flattened amacrine with long and fine processes ramifying mainly in the first and fifth strata; D, amacrine with radiating tuft of fibrils destined for third stratum; E, large amacrine, with processes ramifying in fifth stratum; F, small amacrine, branching in second stratum; G, H, other amacrines destined for fourth stratum; *a*, small ganglion-cell sending its processes to fourth stratum; *b*, a small ganglion-cell with ramifications in three strata; *c*, a small ganglion-cell ramifying in first stratum; *d*, a medium-sized ganglion-cell ramifying in fourth stratum; *e*, giant-cell, branching in third stratum; *f*, a large ganglion-cell with extensive dendrons ending in fourth stratum.

VI. Amacrines and ganglion-cells from the dog. A, amacrine with radiating tuft; B, large amacrine passing to third stratum; C and G, small amacrines with radiations in second stratum; F, small amacrine passing to third stratum; D, amacrine with diffuse arborisation; E, amacrine belonging to fourth stratum; *a*, *d*, *e*, *g*, small ganglion-cells, ramifying in various strata; *b*, *f*, large ganglion-cells, showing two different characters of arborisation; *i*, bi-stratified cell.

VII. Amacrines and ganglion-cells from the dog. A, B, C, small amacrines ramifying in middle of molecular layer; *b*, *d*, *g*, *h*, *i*, small ganglion-cells showing various kinds of arborisation; *f*, a larger cell, similar in character to *g*, but with longer branch; *a*, *c*, *e*, giant-cells with thick branches ramifying in the first, second, and third layers; L, L, ends of bipolars branching over ganglion-cells.

and the fibres of Müller pass through it as fine vertical filaments with delicate lateral offsets.

4. **Inner nuclear layer.**—This is composed of a number of closely packed cells, which are frequently known collectively as the 'inner granules,' but are of several distinct kinds. Some are bipolar nerve-cells, and it is the presence of these which has led to the name *ganglion retinæ* being applied to this layer. They occupy the bulk of the stratum and send processes inwards and outwards into the respective molecular layers. Others are multipolar nerve-cells, the processes of which ramify in the molecular layers; they form incomplete strata close to and partly imbedded in the molecular layers. Others, again, are nucleated enlargements belonging to the fibres of Müller. The structure and arrangements of each of these elements must be separately considered.

a. Bipolar cells.—These, by far the most numerous, are round or oval clear cells (fig. 165, I., III.; fig. 166, 4), prolonged at either end into a fibre.

Of the processes or fibres which proceed from these cells, the inner one, or that extending into the inner molecular layer, is finer than the other, is always unbranched until reaching that layer, and often exhibits varicosities similar to those on nerve-fibrils. It is regarded as the axis-cylinder process of the cell, and extends usually to the inner part of the internal molecular layer, within which it ends in a terminal ramification of varicose fibrils which is frequently in close proximity to the outer surface of one or more of the ganglion-cells of the layer. The outer prolongation or process of the bipolar cell is not varicose, is usually thicker than the inner one, and in some cases passes undivided into the next layer, in others divides before reaching it. Having arrived at the outer molecular layer, it breaks up into an arborisation within this layer, which is interlaced with arborisations of fibres belonging to the horizontal cells presently to be described, and with the terminations of the rod- and cone-elements of the bacillary layer. It has been shown by Cajal that the bipolars are of at least two kinds, distinguishable by the character of the terminal arborescence of the outwardly directed protoplasmic process, and by the position in the internal molecular layer in which the axis-cylinder process terminates. In one kind this arborescence is composed of a dendritic tuft of vertical fibrils, somewhat varicose and enclosing among them the end-knobs of several (three to twenty) of the rod-fibres of the bacillary layer; and the axis-cylinder process ends in a varicose ramification over a body of a cell of the ganglionic layer. These may be termed, therefore, the *rod-bipolars*, or bipolars with vertical arborescence (fig. 165, I. *c*; III. *a*). In the other kind (*cone-bipolars*) this terminal arborescence is horizontal (fig. 165, I. *e*; III. *b*, *c*, *d*, *e*), and abuts against or interlaces with the ramified foot of one or more cone-fibres; the axis-cylinder process usually extends to a less depth of the internal molecular layer, and is not constant in position as is that of the rod-bipolar. The axis-cylinder process of either kind may give off short collaterals in traversing the inner molecular layer. Some of the cone-bipolars (giant bipolars) have their horizontal arborescence extending over a large area of the outer molecular layer (fig. 165, I. *f*; III. *f*, *g*), and probably come into contact with a considerable number of cone-feet.

In birds, reptiles, and amphibia some of the bipolar cells—probably corresponding to those described above as cone-bipolars—give off from their arborescence within the outer molecular layer an unbranched irregularly varicose fibril as far as and just beyond the membrana limitans externa (*fibril of Landolt*), where it usually ends in a clavate enlargement (fig. 166, E). Dogiel described this also in man, but according to Cajal it is absent in mammals and teleosteans.

The relative length of the inner and outer process of the bipolars naturally differs according to the position of the individual cell in the nuclear layer: if the cell is near the inner molecular layer the outer process will have a longer course to reach the outer molecular layer, and conversely if the cell is near the latter. At and near the central fovea these processes or fibres of the inner nuclear layer have a markedly oblique direction; in other parts of the retina they run nearly vertically to the surfaces.

In the frog and lizard it is common to find bipolars among the outer granules as well as in their ordinary position in the inner nuclear layer. Such cells are spoken of as displaced bipolars.

b. Spongioblasts of W. Müller; *amacrine*[1] *cells* of Cajal.—These, which are placed in the inner part of the inner nuclear layer (fig. 166, A, B, C), form an almost complete stratum, which is termed by Cajal the layer of amacrine cells. As this name implies, it has not hitherto proved possible to demonstrate the existence of an axis-cylinder process in many of these cells (which are nevertheless regarded by Cajal as nerve-cells[2]), but they possess, on the other hand, extensively ramified protoplasmic processes which are wholly included within the inner molecular layer, and mostly form horizontal arborisations in the several strata of that layer. There are several kinds of these cells, which differ among one another much in the same way as do the cells of the ganglion-cell layer—that is to say, partly in the varying size of the cell-body and the character of the cell-processes, partly in the position of their terminal arborescences within the inner molecular layer.

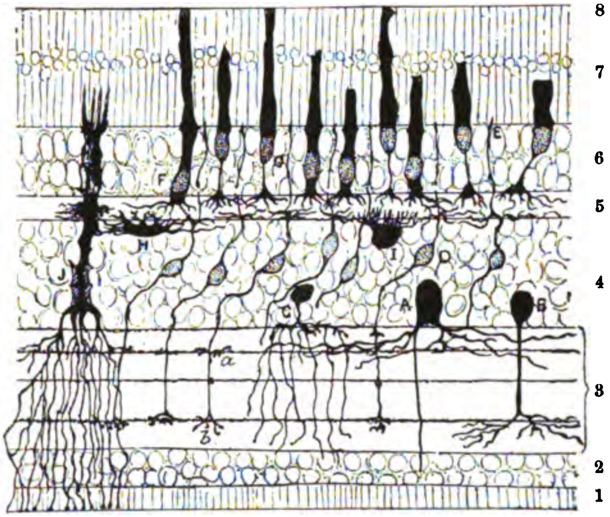

FIG. 166.—SECTION OF BIRD'S RETINA, PREPARED BY GOLGI'S METHOD. (R. y Cajal.)

A, B, large spongioblasts of inner nuclear layer; C, smaller spongioblasts of the same layer; D, small bipolar cells with one process, *a*, *b*, ending in terminal ramifications in the inner molecular layer, and the other process ending partly in a flattened ramification in the outer molecular layer and partly in a filament which ends at the external limiting membrane in an enlarged extremity (at E); F, G, rod- and cone-nuclei; H, I, cells with ramifications in the outer molecular layer; J, fibre of Müller.

The varieties of amacrine cells described by Cajal are, firstly, those with diffusely ramified processes, their arborescence extending throughout the whole depth of the molecular layer

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[1] α, privative; μακρός, long; ἰνός, fibre.

[2] In birds, reptiles, and amphibia there are a certain number of large cells in this layer which have an undoubted axis-cylinder process extending into the nerve-fibre layer (Dogiel) (see fig. 166, A), but they have not been found in mammals.

(fig. 165, I. *h*; VI. D), and secondly, those having their terminal arborescences horizontally placed in the several strata of the molecular layer. Of these so-called stratified amacrines there are, as in the case of the ganglion-cells, three principal types:

(1) Those of the first type (fig. 165, V. B, E; VI. B) have for the most part very large cell-bodies and a thick stalk-like process, sometimes more than one, extending into the inner molecular layer, and ramifying in one or other of its strata over a considerable extent of area, but with comparatively few and relatively coarse processes. A good deal of variation is, however, met with in the character and extent of these processes.

(2) Those of the second type (fig. 165, V. F, G, H; VI. E, F, G; VII. B, C) have a pyriform cell-body of medium size with a straight stalk passing into the molecular layer, and ending in one of its strata in a moderately extended close interlacement of fibrils.

(3) The amacrines of the third type (fig. 165, V. D; VI. C) are of small or medium size, usually with a fine stalk-like process passing into the molecular layer. From the inner end of this process a terminal tuft of very fine radiating fibrils spreads out in one of the strata of the molecular layer, the extent of the arborescence thus formed being often very considerable. When, however, the arborescence is near the inner nuclear layer, the fibrils may come off from the body of the cell (fig. 165, V., VI. A).

c. Spongioblasts of outer molecular layer: horizontal cells of Cajal: basal cells.—These are flattened or irregularly projecting nerve-cells, the bodies of which occupy the outermost part of the inner nuclear layer, whilst their greatly ramified processes extend into and end in the outer molecular layer. The stratum in which they lie is termed by Cajal the layer of horizontal cells; it was previously described by W. Krause as the membrana fenestrata.

Two kinds of these cells have been noticed by Cajal in mammals, and by their situation they serve to subdivide the layer into two strata, an inner and an outer. Both belong to the short-axoned type of nerve-cells.

(1) The cells in the inner stratum of the layer are large and broadly pyramidal in shape, the base being directed towards the outer molecular layer, and resolving itself into a large number of coarse but rapidly tapering processes which end in small tufts of short varicose vertical fibrils at about the level in the outer molecular layer in which the knobs of the rod-fibres occur. The apex of the pyramid is sometimes truncated, but in other cases can be traced as a thick vertical process down into the inner molecular layer, where it ends in horizontal branches. Each cell has an axis-cylinder process, which extends for a considerable distance within the outer molecular layer to end in a closely interlaced terminal ramification (fig. 165, II. B. C; IV. *a*).

(2) Semilunar cells, from the outer flattened surface of which a thick brush of closely interlacing radiating filaments comes off and passes vertically outwards towards the bases of the rod- and cone-fibres (fig. 165, II. A). These also have an axis-cylinder process which passes horizontally and a little upwards to end in the outer part of the outer molecular layer.

5. **Outer molecular layer.**—The outer molecular layer is much thinner than the inner, but otherwise presents, in vertical sections of hardened retina, a similar granular appearance.

This layer (fig. 165, II.) is largely formed of the processes of the horizontal cells which have just been described, and also of the outwardly directed protoplasmic processes of the bipolars, which ramify within it and interlace with similarly ramifying fibres from the cones, and with the knobbed ends of the rod-fibres (fig. 165, I.).

In some mammals there are cells with widely extending branched processes resting upon the outer surface of the outer molecular layer (fig. 165, III. *h*), much in the same way as some of the amacrine cells rest upon the inner molecular. The outer molecular layer also receives fine axis-cylinder processes which pass into it from the inner molecular (fig. 165, I. *i*), but whence they are derived is not known.

The layers hitherto described contain structures (cells and fibres) which are undoubtedly of nervous nature, and which appear to be developed in the same manner as corresponding structures in the brain. They form the *cerebral layer* of Schwalbe. Those next to be described are of epithelial nature, and constitute collectively what was termed by Schwalbe the *neuro-epithelium of the retina*, in contradistinction to the more strictly nervous or cerebral part.[1] The outer nuclear and bacillary layers are morphologically but one, being composed of long cells—*visual cells*—which extend through both layers. Each cell is drawn out into a fibre, and furnished with a nucleus in its inner portion (rod- or cone-fibre and its outer granule), and is peculiarly modified both in shape and structure in its external portion (rod or cone proper).

In most vertebrates no blood-vessels penetrate into this epithelial layer, but a remarkable exception is stated by Denissenko to occur in the retina of the eel, in which the retinal capillaries extend nearly to the limitans externa.

In the cephalopod eye the two layers are separated from one another.[2]

6. **Outer nuclear layer.**—This layer (figs. 163, 165 I., 166) is in most parts of the retina from ·03 to ·04 mm. thick, but considerably more at the sides of the fovea, where, however, it assumes a fibrous character (see p. 245). It resembles very closely at first sight, in sections of retina stained with hæmatoxylin or carmine, the inner nuclear layer; appearing, like that, to consist of clear, oval or elliptical, nuclear corpuscles (outer granules), from the ends of which delicate fibres are prolonged. These outer granules differ, however, essentially from the inner granules and may be readily distinguished from them. They are of two kinds, which present well-marked differences, and are known respectively as the rod-granules and cone-granules, accordingly as they are connected with the rods or with the cones of the next retinal layer. Those which are connected with the *rods* are, in most parts of the retina, by far the more numerous, and form the main thickness of the outer nuclear layer. They may be regarded as enlargements or swellings in the course of delicate fibres (rod-fibres), which extend from the inner ends of the rods at the membrana limitans externa through the thickness of this layer to the outer molecular layer. The enlargements, of which there is but one to a fibre, situated at any part of its course, are each occupied by an elliptical nucleus, and frequently exhibit a remarkable cross-striped appearance (fig. 163, B) (Henle), due, according to Greeff, to the disposition of the strongly refracting chromatic substance of the nuclei. Sometimes the trabeculæ of chromatin are relatively thick and appear as bands with the clear achromatic substance on either side of them, while in other cases the trabeculæ are thinner—the achromatic substance more pronounced. Frequently the chromatin trabeculæ are irregularly distributed as in ordinary resting nuclei. This is most commonly the case in man, the transverse disposition being more often found in many of the lower animals. A nucleolus is nearly always present.

The rod-fibres are of extreme fineness, and exhibit minute varicosities in their course: each is directly continuous at the outer end with one of the rods, but at the inner end terminates in a somewhat larger varicosity (*end-knob*). These end-knobs lie in the outer part of the outer molecular layer, and are imbedded in the tufts of which the terminal arborisations of the rod-bipolars are formed. In amphibia and birds (but not in nocturnal birds) fine fibrils radiate from these end-knobs (fig. 166), but in mammals and teleosteans these radiating fibrils are absent (Cajal).

Those outer granules which are connected with the *cones* are, in most parts of the retina, much fewer in number than the rod-granules, from which they are distinguished by their shape, which is somewhat pyriform, by the absence of transverse striation, and by their position—for they occupy the part of the outer nuclear layer nearest the membrana limitans externa,[3] and the larger end of each is thus in close proximity to the base of the corresponding cone (fig. 167), with

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[1] Schwalbe in Graefe-Saemisch, Handbuch der Augenheilkunde (1st ed.), 1874.

[2] Lenhossék, Arch. f. mikr. Anat. Bd. xlvii. 1896.

[3] In Teleostei the cone-nuclei lie outside the limitans externa. Occasional cones are found in the same situation in other animals and in man (Stöhr, Würzburger Verhandl. xx. 1887).

which it is directly connected, or there is at most a short, comparatively thick stalk uniting the two (see fig. 169). At the macula lutea, however, where only cone-granules are met with, many of them are farther removed from the limiting membrane, and the stalk is then longer and of about the same diameter as the inner segment of the cone (fig. 177). The nucleus of each cone-granule, which, as in the case of the rod-granules, occupies almost all the enlargement, is spheroidal, and contains a distinct nucleolus. The rod-nuclei vary in staining under the influence of light.[1] In Triton they undergo a change of position, tending to project beyond the line of the limitans externa in an eye protected from light, and being withdrawn within its limit after exposure to light. The cone-fibre is very much thicker than the rod-fibre above described, and is itself finely striated or fibrillated. According to Merkel, it has an envelope. It passes from the smaller end of the pear-shaped enlargement straight through the outer nuclear layer to reach the outer molecular layer, upon which it rests by a somewhat pyramidal base (*cone-foot*), from which ramifications may be traced into the substance of the molecular layer, where they interlace with the ramifications of the peripheral processes of the cone-bipolars (see above) (fig. 165, I.).

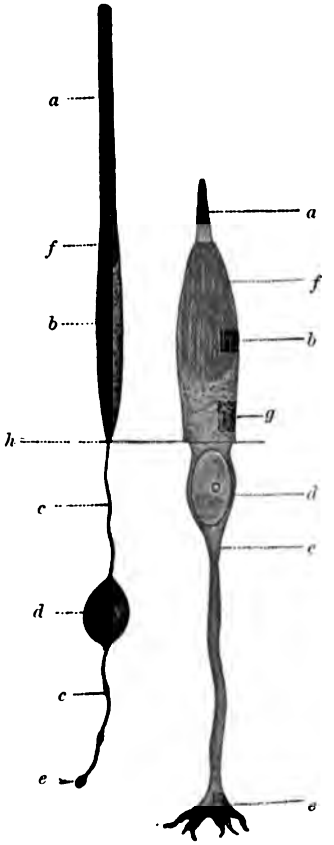

FIG. 167.—A ROD- AND A CONE-ELEMENT FROM THE FUNDUS OF THE HUMAN RETINA, OUTSIDE THE MACULA LUTEA. Magnified 1,000 diameters. (Greeff.)

a, outer segment; *b*, inner segment; *c*, rod- or cone-fibre; *d*, rod- or cone-nucleus; *e*, termination of fibre; *f*, ellipsoid; *g*, myoid (of cone); *h*, limitans externa.

7. **The layer of rods and cones.**—The elements which compose this layer are, as their name implies, of two kinds, those of the one kind—the *rods*—having an elongated cylindrical form (about 0·060 mm. long and 0·002 mm. diameter); the *cones*, on the other hand, being shorter (0·035 mm.), much thicker (0·006 to 0·0075 mm.), and bottle-shaped, being larger at the inner end or base, and terminating externally by a finer tapered portion. Both rods and cones are closely set in a palisade-like manner over the whole extent of the retina between the membrana limitans externa and the pigmentary layer (fig. 163, 7). Except at the macula lutea and central fovea (in the latter only cones are met with) the rods far exceed the cones in number. According to Fritsch, the foveal cones are so closely packed as to give the appearance in section of a hexagonal mosaic. A similar appearance is represented by Heine.[2] Their relative number and arrangement is well exhibited when the layer is viewed from the outer surface, as in fig. 168, where *a* represents a portion of the layer from the central fovea; *b*, a little removed from the centre; and *c*, from the peripheral part of the macula.

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[1] G. Mann, Journ. Anat. and Physiol. xxix. 1894.

[2] Arch. f. Ophth. 1905. Other authors have regarded this mosaic appearance as an artifact.

Greeff[1] states that near the periphery of the retina the rods are smaller, and measure 0·050 mm., and close to the ora serrata only 0·040 mm. On the other hand, the cones become thicker and shorter as they are traced forwards (fig. 169).

The total number of cones in the human retina has been calculated to amount to seven millions, and of rods to 130 millions (W. Krause).[2] Salzer[3] reckoned that there are about half this number of each. In any case there are far more rods and cones than fibres in the optic nerve, the number of which is put by Salzer at about half a million.

The rods and the cones, although differing thus in shape and size, agree in many points of structure. Thus, each consists of two distinct segments—an inner and an outer; the division between the two occurring, in the case of the rods, about the middle of their length (in man); in the cones at the junction of the finer tapering end-piece with the basal part; consequently, the outer and inner segments of the rods are not very dissimilar in size and shape, the inner being, however, slightly bulged; whereas the inner segment of each cone far exceeds the outer one in size, the latter appearing merely as an appendage of the inner segment (fig. 167). Between the two segments in both rods and cones is a thin clear 'intermediate disk' (Greeff). The two segments both of the rods and cones exhibit well-marked differences in their chemical and optical characters, as well as in the structural appearances which may be observed in them. Thus, while in both the outer segment is doubly refracting in its action upon light, the inner is, on the contrary, singly refracting: the inner becomes stained by carmine, iodine, and many other colouring fluids, while the outer remains uncoloured by these reagents, but is stained greenish-brown by osmic acid. The outer segment in both shows a tendency to break up into a number of minute superposed disks about 0·0005 mm. thick, which are an integral part of its structure (fig. 163, B), and probably have the function of arresting rays of light. The inner segment of each rod and cone is distinguishable into two parts (fig. 167)—an outer part, composed, according to Max Schultze, of fine fibrils; and an inner part, homogeneous, or finely granular, and, at the membrana limitans externa, directly continued into a rod- or cone-fibre, the disposition of which in the outer nuclear layer has been already described.

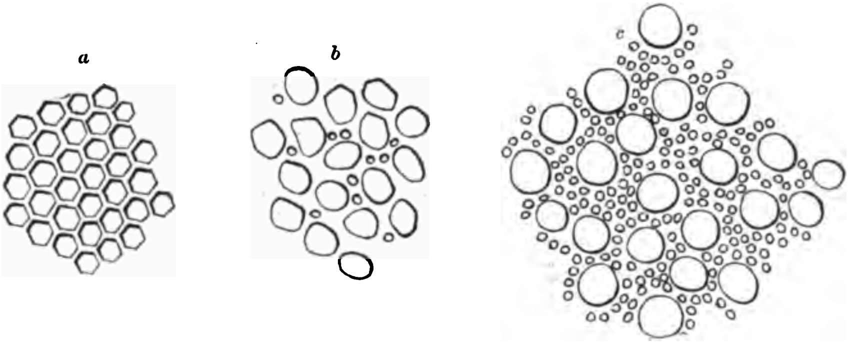

FIG. 168.—SECTIONAL VIEWS, SHOWING THE RELATIVE NUMBER, SIZE, AND ARRANGEMENT OF THE RETINAL CONES IN THE FOVEAL PART OF THE HUMAN RETINA. Magnified 950 diameters. (Heine.)

a, from the centre of the fovea: here the cones appear compressed into an angular shape in section; *b*, from half-way between the centre and the margin; *c*, from the margin of the fovea.

In the **outer segments** of the *rods* there can be detected, by the aid of a powerful microscope, besides a delicate transverse striation, corresponding to the superposed disks of which, as above mentioned, they appear to be formed, fine longitudinal markings which are due to slight linear grooves by which they are marked in their whole extent. The ends of the segments are rounded

[1] Graefe-Saemisch, Handb. d. Augenheilk. (2nd ed.).

[2] Handbuch der menschl. Anat. 1879.

[3] Wiener Sitzungsb. 1880.

and project into the pigmentary layer. The purplish-red colour of the retina before mentioned (p. 225) resides entirely in the outer segments of the rods

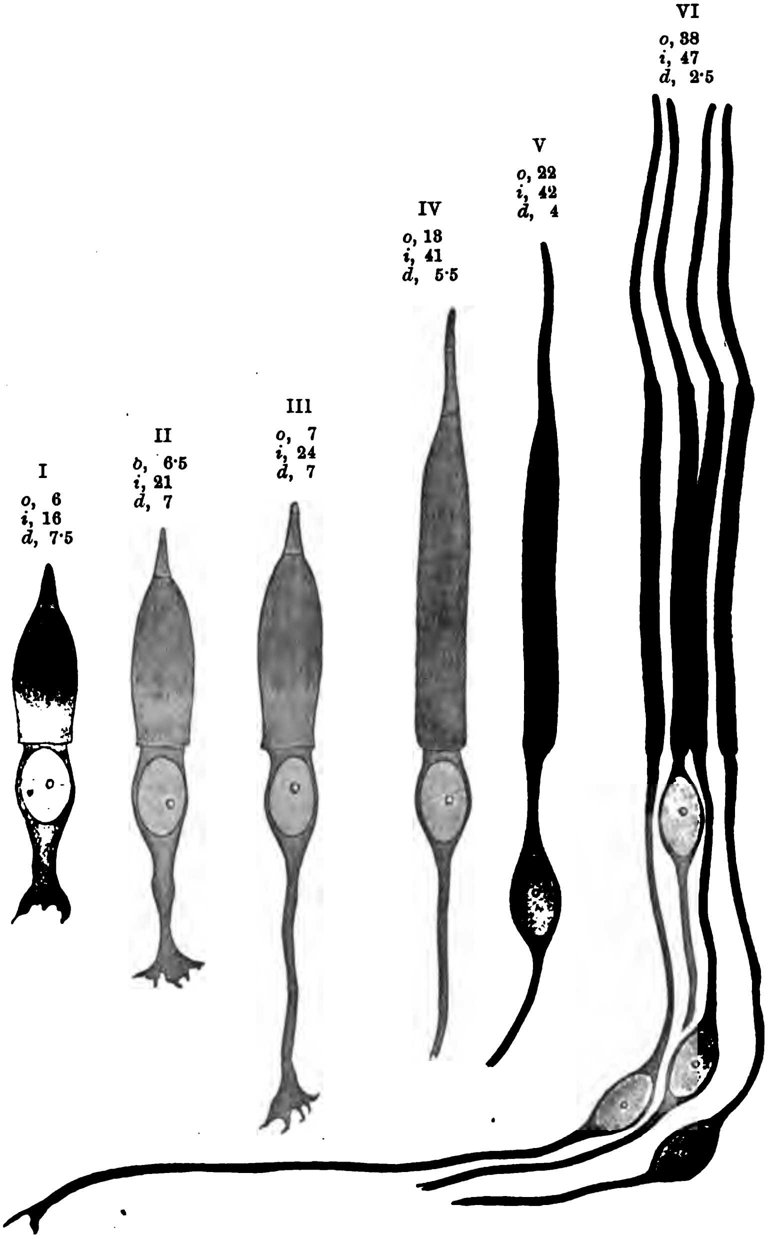

FIG. 169.—CONES FROM DIFFERENT REGIONS OF THE HUMAN RETINA. Magnified 1,000 diameters. (Greeff.)

The measurements in micromillimetres of the outer and inner segments and of the diameter of the inner segment are appended to each.

I, From close to the ora serrata; II, from 2 mm. farther back; III, from the equatorial region; IV, from the periphery of the macula lutea; V, from near the margin of the fovea; VI, from the central part of the fovea.[1]

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[1] In VI the inner segments should be represented shorter, and the outer longer. Moreover, the fibres which extend down from the inner segments as far as the nuclei should be represented of the same diameter as the inner segments (see fig. 177).—E. A. S.

(Boll, Kühne). A few of the rods are in some animals (frog, toad) of a green colour; they have a short outer and a long and filiform inner segment. The outer segments of the *cones* taper gradually to a blunt point, and do not exhibit superficial groovings, but the transverse markings are somewhat more evident than in the rods (figs. 163, 169). There is a delicate covering of neurokeratin investing the outer segments of both rods and cones; this is somewhat more pronounced on the cones, so that a post-mortem separation into discs does not take place so readily as in the rods. Hesse[1] describes spiral fibrils lying within the sheaths of both rods and cones. W. Krause[2] and Schneider[3] have described spiral fibrils in the rods; but Greeff[4] failed to confirm this observation, and the appearance may be due to post-mortem changes. Howard[5] finds longitudinal fibrils in the outer segments of the rods of the frog (*Rana pipiens*). From their behaviour to staining reagents and the readiness with which they become altered after removal from the body, it has been conjectured that the outer segment contains materials similar in chemical nature to, but not identical with, those composing the myelin of the medullary sheath of nerve-fibres.

The red colouring-matter of the rods (rhodopsin, Kühne) is bleached by light. It occurs in nearly all Vertebrata, but in no Invertebrata. It is also absent in one bat (although usually well marked in nocturnal animals) and in some diurnal birds (hen, pigeon). None is found in rods within 3 mm. of the ora serrata. It occurs in the fœtus at seven months.

In the **inner segments**, the proportion which the fibrillated part bears to the homogeneous basal part differs in the rods and cones. In the *rods* the fibrils usually occupy only the outer third of the inner segment (fig. 163, B), ceasing abruptly at its junction with the middle third; in the *cones*, on the other hand, they occupy about the outer two-thirds of the segment; only the part nearest the membrana limitans remaining free from fibrils, the relative extent of the fibrillated part ('ellipsoid') and the non-fibrillated ('cone-myoid') varying, however, with the amount of contraction or extension of the cone-myoid (see next page). The fibrils of the ellipsoid are for the most part straight and parallel, and strongly refracting; they sometimes form a close feltwork. In the cones of some mammals, instead of this outer part of the inner segment being fibrillated, it appears homogeneous, but is well marked off from the inner part by its strong refractivity.

This homogeneous condition of a part of the inner segment of the *cones* is much better marked in lower Vertebrata, where there occurs a distinct strongly refracting body, situated either in the middle or in the outer part of the inner segment, which has long been termed from its shape the 'ellipsoid,' a name which is also extended to include the fibrillated outer part of the segment in the human retina. In reptiles an oval body, coloured red by iodine, takes the place of the ellipsoid (Merkel). It is stated by Birnbacher[6] that (in the perch) the ellipsoid, which in the 'dark' eye stains with eosin, loses this faculty after exposure to light. In lower vertebrates, as well as in most mammals, fibrils are also absent from the inner segments of the *rods*, a peculiar, strongly refracting, plano-convex lens-like body ('rod-ellipsoid') being met with at their outer part, corresponding in situation to the ellipsoid of the cones, but smaller than that structure. It is well seen in the frog. Further, in birds, reptiles, and some amphibia, in ganoid fishes and in marsupials (but not in other mammals), there is found in the extreme outer part of the inner segment of each *cone* a minute globular body, apparently of a fatty nature, which in some is clear and colourless, but in many cones is brightly coloured of a tint varying in different cones from red, through yellow, to bluish-green—red and yellow being the most common. Blue and violet are not met with, but by the action of iodine the colours of all become changed to blue. In some birds the oil-globule is colourless, in others red, yellow, yellowish-

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[1] Festschr. f. August Weismann, 1903.

[2] Int. Monatschr. f. Anat. u. Phys. ix. and x. 1892, 1893.

[3] Arb. Zool. Instit. Wien, 16, 1904.

[4] *Op. cit.*

[5] Amer. Naturalist, vol. xxxvii. 1903. Kolmer, Anat. Anz. xxv. 1904, and Held, Abhandl. d. k. Sächs. Ges. f. Wiss. xxix. 1904, describe a single excentric longitudinal fibril in the outer segments of both rods and cones.

[6] Arch. f. Ophth. xl. 1894.

green, or bluish-green.[1] Sometimes the whole inner segment is found to be pervaded with granules tinted of the same colour as the 'oil-globule.' In birds there are two kinds of cone, both of small size: in the one kind, the cone-fibre passes straight down to the outer molecular layer; in the second kind, obliquely. In all vertebrates below mammals, double or twin-cones are here and there met with; these usually have, the one a straight, the other an oblique cone-fibre. Numerous other differences and peculiarities are found in animals; thus in birds and reptiles the cones are more numerous than the rods; in many reptiles (*e.g.* lizard) only cones are met with; while in some fishes (sharks and rays), in most nocturnal mammals, and in the owl, the cones are either altogether absent or are but few and rudimentary (M. Schultze). In the size of the elements there is also much variation: the rods being very large in amphibia, and long in fishes. In the frog there are three kinds of rod, one kind having a long outer segment of the usual red colour (when not exposed to light), while in the others the inner segment is the longer, and either fine or of the usual thickness, while the outer segment is short and of a green colour. The rod-fibre is straight in the red variety and in those of the green kind with the larger inner segments, but oblique in the green rods with finer inner segments.

In the frog the inner segments of the cones were observed by Engelmann and Van Genderen-Stort[2] to shorten on exposure to light and to lengthen in the dark (fig. 172). The contraction shows itself almost exclusively in the part of the inner segment lying between the ellipsoid and the limitans externa, on which account this part was termed 'myoid' by Engelmann. In the frog and fish it may contract under the influence of light to one-tenth the length it exhibits after prolonged keeping of the eye in total darkness. The movement is slow: it takes in the frog one minute to be at all perceptible[3]; but a very weak light, if acting long enough, is effective in producing contraction. A retina which has been exposed to light yields an extract which will cause contraction of the cones of one which has been protected from light. According to Engelmann, green light has more effect than red or yellow of equal intensity, and has further most effect on those cones which possess red oil-globules. The change will take place if the head of the animal be kept in the dark and only the skin of the trunk and limbs exposed to the action of light.[4]

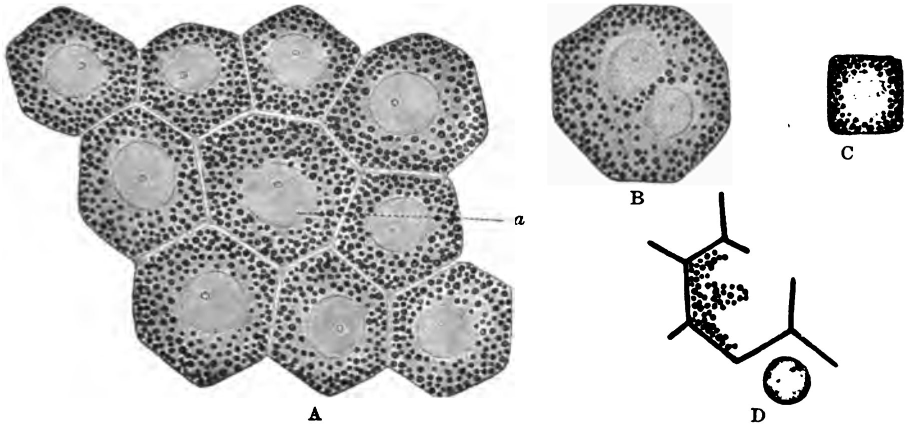

FIG. 170.—PIGMENT-EPITHELIUM FROM THE HUMAN RETINA. Magnified 1,000 diameters. (Greeff.)

A, surface view, showing ten cells, mostly hexagonal, but one or two pentagonal and heptagonal (*a*); B, a large eight-sided cell with two nuclei; C, a small quadrilateral cell; D, a portion of the intercellular substance isolated, but with cell-fragments adhering to it.

The inner segments of the rods have been described as undergoing a slight contraction under the influence of light in fishes. In other animals (pigeon) they are said to become vacuolated and lengthened, while their outer segments tend to swell. Lederer found the rods in the frog becoming longer and thinner and staining more deeply with osmic acid after exposure to light.[5]

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[1] For many interesting details regarding the distribution of the coloured globules in birds, see Waelchi, Arch. f. Ophth. xxix. 1883.

[2] Arch. f. Ophth. xxxiii. 1887.

[3] Pergens, Tr. de l'instit. Solvay, i. 1896.

[4] Engelmann, Pflüger's Arch. xxxv. 1885. Cf. A. E. Fick, Arch. f. Ophth. xxxvii. 1891.

[5] Centr. f. Physiol. xxii. p. 762, 1909.

8. **The pigmentary layer.**—This layer, which bounds the retina externally, and was formerly described with the choroid coat, consists of a single stratum of hexagonal epithelium-cells separated from one another by a perceptible amount of clear intercellular substance (fig. 170). The cells average 12 μ to 18 μ in diameter (Kölliker), but are much smaller in the region of the macula than elsewhere. The outer surface of each cell—that which is turned towards the choroid—is smooth and flattened, or slightly convex, and the part of the cell near this surface may be devoid of pigment; it contains the nucleus (figs. 171, 172). The inner boundary, on the other hand, is not well marked, for the substance of the cell, which here is loaded with pigment, is prolonged into fine, straight, filamentous processes (fig. 171, A), which extend for a certain distance between and among the outer segments of the rods and cones; indeed, the outer parts of the rods may be said to be altogether imbedded in the pigment-cells (B). In man and mammals the filamentous processes pass only for a short distance towards the limitans externa, but in oviparous vertebrates they reach the inner segments of the rods, or even, in light-adapted eyes, the limitans externa.

The pigment-cells are not everywhere regularly hexagonal, but here and there cells are found, singly or in patches, which are larger or smaller than the rest, and of a more rounded or of an irregularly angular shape.[1]

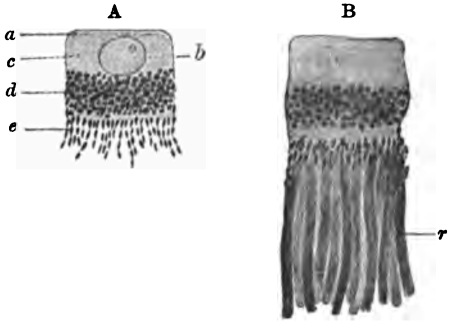

Fig. 171.—Two pigment-cells from the human retina, in profile view. Magnified 1,000 diameters. (Greeff.)

A, an isolated cell represented schematically. *a*, domed free surface, with superficial layer of neurokeratin; *b*, nucleus; *c*, pigment-free cytoplasm; *d*, pigmented cytoplasm; *e*, pigment-containing processes, extending towards limitans externa. B, a cell with a large number of outer segments of rods (*r*) still adhering to it. (From an osmic-acid preparation.)

The pigment-granules, many of which are in the form of minute crystals of a brown material, known as *fuscin* (Kühne), are placed for the most part, both in the cells and cell-processes, with their long axes at right-angles to the surface of the retina. The distribution of the pigment-granules within the cells varies during life and immediately after removal of the eye according as the retina has been shaded from the light or exposed to its influence (Boll[2]; Kühne[3]). In the former case the pigment is mainly accumulated in the body of the cell (or at least its inner zone), and is withdrawn to a great extent from between the rods; but after exposure to light, a large amount of pigment is found between the rods, and some of the granules may even extend in the frog as far as the external limiting membrane (fig. 172). This has the effect of causing the pigmentary layer to adhere more firmly to the rest of the retina than when the pigment-granules are accumulated in the body of the pigment-cell. The pigment appears to have, *inter alia*, the function of renewing the colour (visual purple) of the outer segments of the rods after these have become bleached from exposure to the light. This renewal of the colour will take place for a short time after the death of the animal, or the excision of the eye (Kühne).

The movements of the pigment are less marked and much more difficult of observation in mammals than in lower Vertebrata. They are noticeable in cephalopods. No movement has been observed in the retina of animals which have only cones. The fuscin itself undergoes some loss of colour in strong light. The movement is slow, the granules taking an hour to extend completely between the rods, and rather more to return to the cell-body. It demands a stronger light than does the contraction of the cones. As with the contraction of the cones, there is a coincident movement of the pigment-granules of the opposite eye, for, if one eye be exposed to light and the other kept protected from light, the pigment in both will be found occupying the 'light' position. This is even the case (Engelmann) if the body of the frog be exposed to light and the eyes and head protected from it. It is generally considered that these synergic effects are due to reflex action, the impulses being conveyed to the darkened eye by efferent nerve-fibres, which are known to pass to the retina to a certain extent. But the observation of E. Fick,[1] who found that on allowing light to fall for some time on one eye the movement of pigment occurred in the other even after the optic nerve had been cut on the side protected from light, suggests the possibility of the operation of a chemical stimulus passing into the circulation.[2]

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[1] Boden and Sprawson, Quart. Journ. Micr. Sc. xxxiii. 1892.
[2] Arch. f. Physiol. 1877.
[3] Heidelberger Unters. 1877.

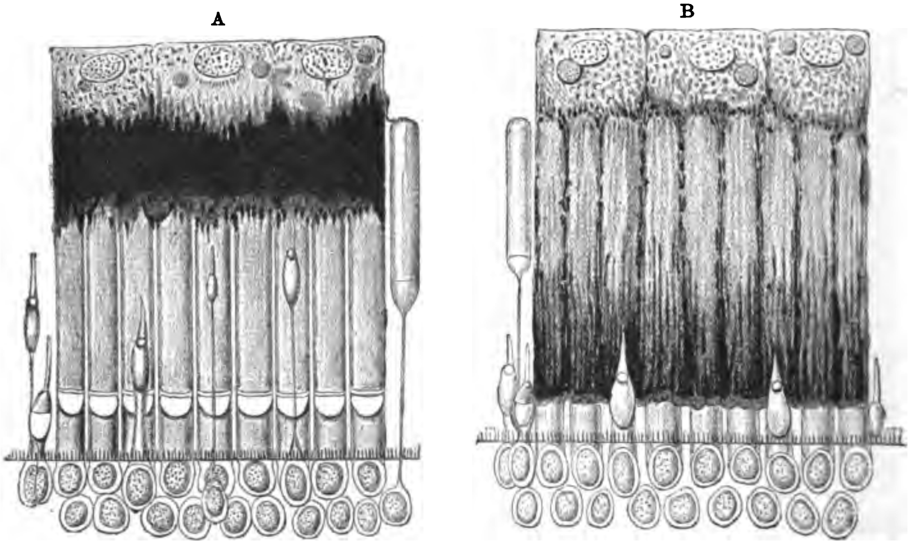

FIG. 172.—SECTIONS OF FROG'S RETINA SHOWING THE ACTION OF LIGHT UPON THE PIGMENT-CELLS, AND UPON THE RODS AND CONES. Highly magnified. (v. Genderen-Stort.)

A, from a frog which had been kept in the dark for some hours before death. B, from a frog which had been exposed to light just before being killed. Three pigment-cells are shown in each section. In A the pigment is collected towards the body of the cell; in B it extends nearly to the bases of the rods. In A the rods, outer segments, were coloured red (the detached one green); in B they had become bleached. In A the cones, which in the frog are much smaller than the rods, are mostly elongated; in B they are all contracted.

In some animals, but not in man, yellow fatty droplets (*lipochrin*, Kühne) (fig. 172), which tend to bleach after exposure to strong light, and particles of a highly refracting myelin-like substance (*myeloid granules*, Ewald and Kühne) occur in the non-pigmented portion of the cells, which are further covered next to the choroid by a clear homogeneous cuticular layer.

In some fishes (*e.g.* Abramis brama) there occur in the pigment-cells in certain parts of the retina numerous granules of a material composed mainly or entirely of guanin, which give a glistening appearance to the back of the eye as seen through the pupil. This was termed by Brücke *pseudo-tapetum*, by Kühne *retinal tapetum*. The guanin, like the pigment with which it co-exists, also shifts its position according as the eye is kept in the dark or light (Exner and Januschke).[3]

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[1] Vierteljahrschr. f. d. Naturfor.-Ges. zu Zürich, xl. 1895.

[2] A full account of the changes which occur in the retina as the result of excitation by light will be found in the article by S. Garten in Graefe-Saemisch, Handbuch (2nd ed.). The article contains a bibliography of the subject up to 1907.

[3] Wiener Sitzungsb. cxiv. 1905.

The intervals between the rods and cones are only partially filled by the processes of the hexagonal pigment-cells; the remaining part appears to be occupied by a clear substance, which, according to Henle and H. Müller, is of a soft elastic consistence during life and in the fresh condition, but soon liquefies after death; but according to Schwalbe is normally liquid. In the embryo, between the hexagonal pigment-cells and the remainder of the retina there is a distinct cleft filled with fluid (remains of cavity of primary optic vesicle), homologous with the ventricular cavities of the brain, with which it is originally in continuity.

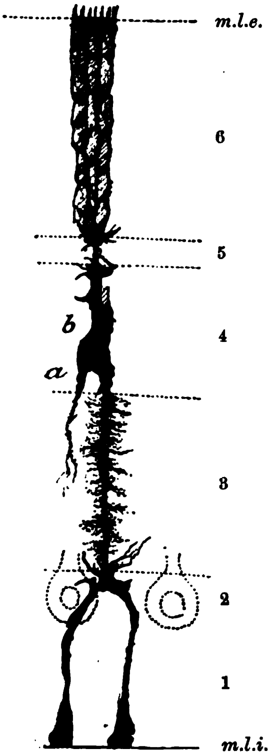

Fig. 173.—A fibre of Müller from the dog's retina, shown by Golgi's method. Highly magnified. (R. y Cajal.)

1, nerve-fibre layer; 2, ganglionic layer; 3, inner molecular layer; 4, inner nuclear layer; 5, outer molecular layer; 6, outer nuclear layer; *m.l.e.*, membrana limitans externa; *m.l.i.*, membrana limitans interna; *b*, nucleus of the fibre; *a*, process extending from nucleated part into inner molecular layer.

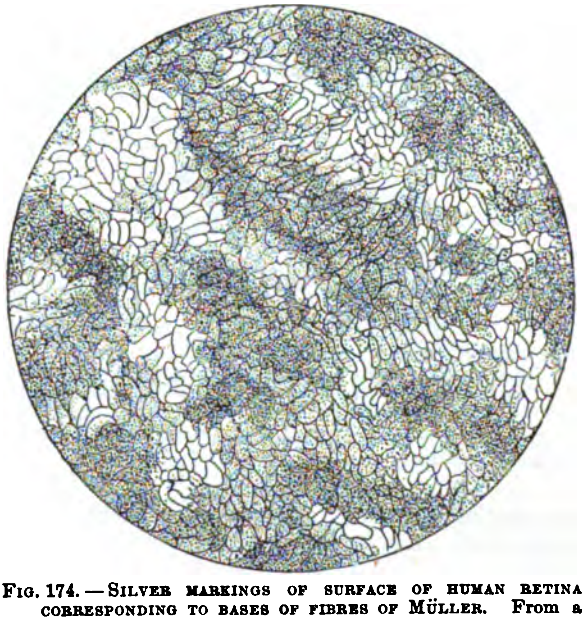

Fig. 174.—Silver markings of surface of human retina corresponding to bases of fibres of Müller. From a preparation by Norris. Magnified 850 diameters. (Piersol.)

The sustentacular tissue of the retina: Müllerian or radial fibres: neuroglia.—In addition to the elements which belong specially to the layers above described, there are certain other structures which are common to nearly all the layers, passing through the thickness of the retina from the inner almost to the outer surface, and, although not of the nature of connective tissue, serving the same kind of purpose—namely, to bind together and support the more delicate nervous structures of the membrane. These *sustentacular fibres* or *fibres of H. Müller* (figs. 166, 173) commence at the inner surface of the retina by a broad conical hollow base or foot, which may be forked (fig. 173), and often contains a spheroidal body, staining with hæmatoxylin (pseudo-nucleus). The bases of adjoining fibres are united together at their edges (figs. 174, 175), so as to give, in vertical sections of the retina, the appearance of a distinct boundary-line (fig. 163 A); this has been named *membrana limitans interna*, but, as may be inferred from the above description, it is in no way a continuous or independent membrane. The Müllerian fibres pass through the nerve and ganglionic layers, either with a smooth contour, or with but two or three well-marked lateral projections, from which fine lamellar processes extend among the elements of these layers; gradually diminishing in size they then traverse the inner molecular layer. In the mammalian retina the fibres may be marked by slight projections in passing through this layer (fig. 173). In the inner nuclear layer they again give off delicate flattened processes from their sides, which pass round the inner granules and serve to support them. Moreover, each Müllerian fibre is here characterised by the presence of a clear oval or elliptical nucleus (already mentioned in the description of the inner nuclear layer), containing a nucleolus, and situated at one side of, and in close adherence to, the fibre to which it belongs (fig. 173, *b*). On reaching the outer nuclear layer (after passing through the outer molecular) the fibres of Müller break up into fibrils and thin lamellæ, and in this form they pass outwards through the layer, between the outer granules and the rod- and cone-fibres, enclosing these structures, filling up the intervals between the granules, and forming partial sheaths for them. At the level of the bases or central ends of the cones and rods, the numerous offsets terminate along a definite line which marks the boundary between the outer nuclear layer and the layer of rods and cones, and has been termed *membrana limitans externa*. This also, like the *m. l. interna*, is in no way a continuous membrane, nor is it isolable from the Müllerian fibres; indeed, numerous fine fibrillar offsets of these pass a short distance beyond the so-called limiting membrane, and closely invest the bases of the inner segments of the rods and cones.

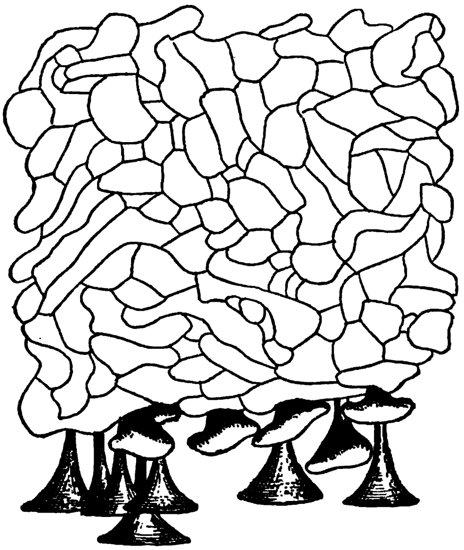

FIG. 175. — INTERNAL LIMITING MEMBRANE OF THE RETINA TREATED WITH SILVER NITRATE, SHOWING THE OUTLINES OF THE BASES OF THE MÜLLERIAN FIBRES. (Retzius.)

At the lower part of the figure some of these fibres are seen separated.

The Müllerian fibres exhibit a fine striation. They swell up and become indistinct on treatment with acetic acid and dilute alkalies, but much more slowly than connective-tissue fibrils; moreover, they are not dissolved by boiling in water. They are much less developed in the central and posterior part of the retina than in the peripheral and anterior part; towards the ora serrata they are very distinct and closely set. In the macula and fovea they have an oblique direction conformably with the nervous elements which they support, and they are much subdivided as they pass between the numerous nerve-cells of the ganglionic layer. The obliquity is most pronounced in the outer fibrous layer (see next page).

The Müllerian fibres are of the nature of neuroglia-cells. A few other neuroglia-cells of a stellate shape (spider-cells) occur in the nerve-fibre layer and occasionally in the ganglionic layer.

Structure of the macula lutea and fovea centralis (figs. 176, 177).—The peculiarities in structure which these present have partly been incidentally noticed in the preceding description of the retinal layers. At the fovea no rods are met with, and the cones, especially their inner segments, are much longer and narrower than elsewhere.[1] All the other layers are much thinned, but towards the margin of the fovea they rapidly increase in thickness, and in the rest of the macula lutea most of them are thicker than at any other part of the retina. The ganglionic layer (fig. 177, 2) is especially thickened at the edge of the fovea, the cells being from six to eight deep. They are smaller here than nearer the centre of the fovea. The nerve-fibre layer (1) gradually thins and disappears as a distinct layer near the edge of the fovea as the fibres join the central ends of the ganglion-cells. The opposite end of each ganglion-cell is directed vertically towards the inner nuclear layer. The bipolar inner granules are somewhat obliquely disposed. They are smaller than the outer granules and, as elsewhere, much smaller than the ganglion-cells. At the centre of the fovea they are but thinly scattered, and the inner and outer molecular layers appear to join between them. At the middle of the fovea the retina is very thin, consisting here mainly of the cone-cells (*i.e.* cones with their nucleated fibres) and pigmentary layer, but a few of the inner granules are also present, and one or two isolated nerve-cells (perhaps amacrine cells) may also be seen very near to the centre. According to the figures and description given by M. Schultze, the membrana limitans externa is also cupped in at this place, and the cones, both inner and outer segments, are considerably longer than elsewhere, so that the line of pigment remains level. Hulke figured the limitans externa as plane, and others (*e.g.* Merkel, Kuhnt, Schwalbe) have denied this cupping of the membrana limitans externa. Undoubtedly, however, it exists (fig. 176), and the cupping may be as deep as that of the limitans interna or true fovea, from which for purposes of description it may be distinguished by the name of *fovea externa.* It measures rather less than 1 mm. in diameter, and is therefore a little smaller than the fovea interna. The inner segments of the cones are not longer here than elsewhere, but are if anything somewhat shorter than at the edge of the fovea; but this is more than compensated for by the greater length of their outer segments. The cones are also more slender in the very middle of the fovea than elsewhere, here measuring not more than 0·002 mm., whereas at the edge of the fovea they are double this in diameter. They are also so closely packed as to produce in cross-section the appearance of a mosaic of hexagonal prisms (Heine) (see p. 236). The outer nuclear layer (fig. 177, 6) of the macula lutea is occupied in the greater part of its thickness by the very long and obliquely disposed cone-fibres; the nuclei are only two or three deep, and take up a comparatively small portion of the layer, which was termed the *outer fibrous layer* by Henle. Over most of the yellow spot the cone-nuclei are placed close up to the limitans externa, but a short distance from the middle of the fovea they begin to be removed from the limitans, and at the centre of the

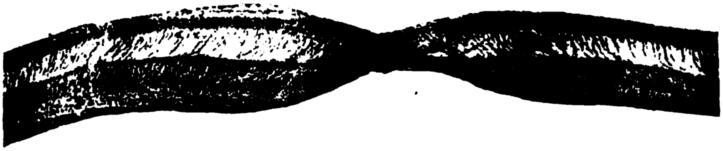

FIG. 176.—SECTION THROUGH THE HUMAN FOVEA AND MACULA. Magnified 85 diameters. (Photographed from a preparation by C. H. Golding-Bird.)

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[1] On the distribution of the rods and cones in the macula region, see Koster, Arch. d'ophthalm. xv. 1895, and Rochon-Duvigneaud, Archives d'anat. micr. t. ix. 1907.

fovea they are close to the outer molecular layer. The parts of the cone-fibres which lie external to their nuclei are of nearly or quite the same diameter as the inner segments of the cones. The cells of the pigmentary layer are smaller but deeper (0·01 mm. × 0·016 mm.) and more strongly pigmented in the macula lutea than in the rest of the retina.[1]

The hyaloid membrane of the vitreous humour is very thin over the centre of the fovea. The choroid coat is thickened opposite the fovea, the thickening being due to an accumulation of capillary blood-vessels, which here occupy not only their usual position, but also that of the layer of larger blood-vessels, and even encroach on the lamina suprachoroidea (Nuël).[2]

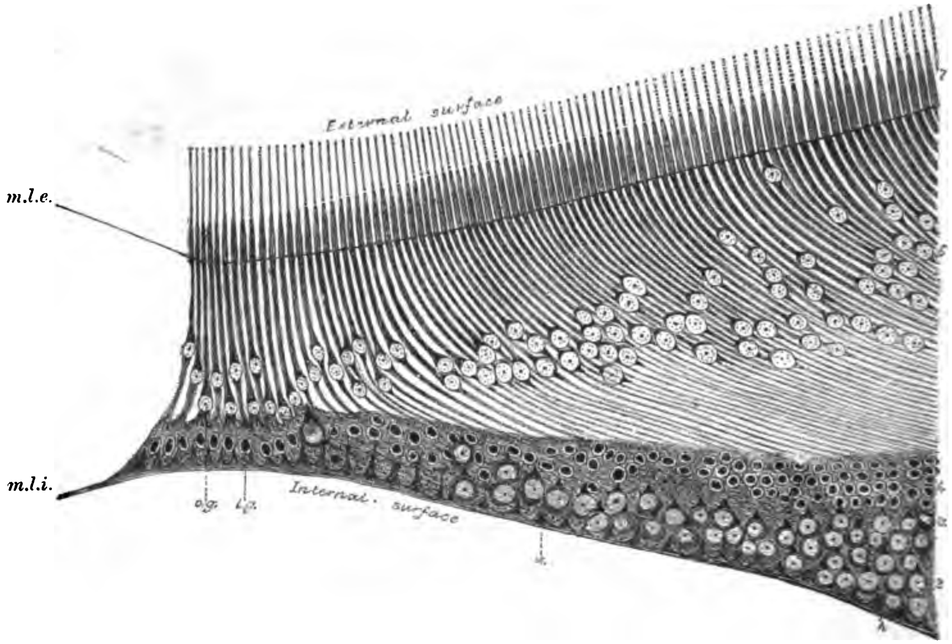

FIG. 177.—DIAGRAM OF A SECTION THROUGH THE FOVEA CENTRALIS. (The outlines of this figure have been traced from a photograph.) Magnified 850 diameters. (From a preparation by C. H. Golding-Bird.)

2, ganglionic layer; 4, inner nuclear; 6, outer nuclear layer, the cone-fibres forming the so-called external fibrous layer; 7, cones; *m.l.e.*, membrana limitans externa; *m.l.i.*, membrana limitans interna.

The yellow tint of the macula is not absent at the centre of the fovea, as has often been thought, but merely less conspicuous here, owing to the thinness of the layers. The colour is said to be due to a diffuse colouring-matter which is seated in the interstices between the elements of the four or five inner layers, but it is by no means certain that it is confined to the interstices. The yellow colour of this part of the retina is peculiar to Primates: in man it develops after birth. A corresponding area, without yellow colour, and usually without fovea, is found in all mammals and is characterised by a lack of dark pigment in the pigmentary layer; but in some mammals (Chievitz), as well as in birds, reptiles, and amphibia (H. Müller, Hulke, W. Krause), a fovea has been described within such a central area. In some birds two foveæ are present, one being near the ora serrata; in some cases several foveæ are found (Chievitz). The central area is always characterised by containing relatively smaller visual cells. The occurrence and relative development of the central area and fovea in Vertebrata has been especially studied by Chievitz,[1] and in man and apes by Fritsch.

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[1] For details relating to the structure of the fovea and its elements, see Dimmer, Beitr. z. Anat. u. Phys. der Macula lutea, 1894; and Golding Bird and Schäfer, Internat. Monatschr. f. Anat. u. Phys. 1895. The external fovea was figured by Max Schultze and described by Ciaccio (Rend. d. acc. d. sci. d. istituto di Bologna, 1880), and also by Wadsworth (Beitr. z. Ophth. Fr. Horner gewidmet, 1881) and by Golding Bird and Schäfer (*loc. cit.*). With their description that of G. Lindsay Johnson (Arch. of Ophthalm. xxv. 1896) agrees generally. Cf. also Greeff (Ber. d. Vers. d. ophth. Gesel., Heidelberg, 1902). Dimmer (*ibid.*) considers the external fovea an artifact, but it is not easy to understand how such an appearance can be produced artificially. The depth of the fovea externa, like that of the fovea interna, appears to vary in individual cases.

[2] Arch. d'ophth. xii. 1892.

Structure of the ora serrata and pars ciliaris retinæ.[2]—At the line of the *ora serrata* the numerous complex layers of the retina disappear, and in front of it the retina is represented merely by a single stratum of elongated columnar cells with a pigmentary layer external to it (*pars ciliaris retinæ*). The transition is, in man, somewhat abrupt, all the changes being met within a zone of about 0·1 mm. in breadth. The layer of rods and cones (fig. 178, *b*) first disappears as a complete layer, the cones continuing rather farther than the rods, but being imperfectly formed and lacking the outer segments; the nerve and ganglionic layers (*g*), which were already very thin and incomplete, cease altogether at the ora; the inner molecular layer (*f*), which is now largely occupied by Müllerian fibres, retains its thickness nearly up to the ora, and then abruptly terminates, as do also the outer and inner nuclear layers (*e*, *c*). The columnar cells of the pars ciliaris, which appear directly to continue these layers of the retina, are at first of considerable length, but become gradually shorter anteriorly; they are finely striated (fig. 179, 2); each cell has an oval nucleus at the outer part of the cell, near the pigmentary layer. The inner end may be rounded, pointed, square, or even branched; the sides of the cells, too, are sometimes uneven. The layer of

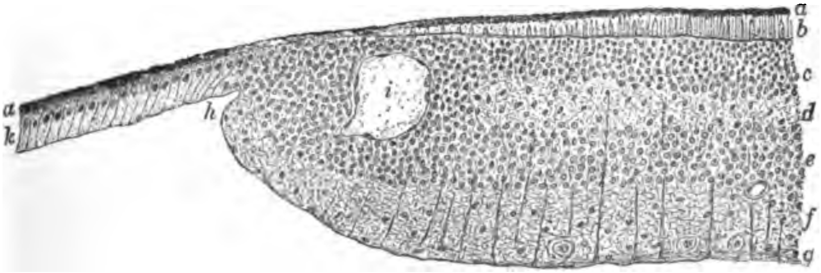

FIG. 178.—SECTION OF HUMAN RETINA AT THE ORA SERRATA, SHOWING THE ABRUPT TERMINATION OF THE USUAL RETINAL LAYERS AND THE CONTINUATION OF THE RETINAL SHEET AS THE PARS CILIARIS. Magnified 165 diameters. (Piersol.)

a, pigment-layer; *b*, rods and cones; *c*, outer nuclear layer; *d*, outer plexiform; *e*, inner nuclear; *f*, inner plexiform; *g*, nerve- and ganglion-layers; *h*, point of transition; *k*, inner stratum of pars ciliaris; *i*, section of cyst (a common appearance at the ora serrata).

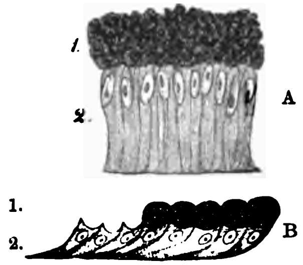

FIG. 179.—A SMALL PORTION OF THE CILIARY PART OF THE RETINA. 850 diameters. (Kölliker.)

A, human. B, from the ox. 1, pigment-cells; 2, columnar cells.

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[1] Chievitz, Arch. f. Anat. (u. Physiol.), 1889, 1891; G. Fritsch, Die Area centralis des Menschen, &c., Berlin, 1908. Fritsch finds great variation in the depth and extent of the fovea in different individuals. He found no fovea in an albino (negro), but its place was occupied by an area centralis. A. König (quoted by Fritsch) had previously noted absence of fovea in albinos (ophthalmoscopic observations).

[2] On the structure of these parts, see O. Schultze, Würzb. Verhandl. xxxiv.; and Schoen, Anat. Anzeiger, x., and Arch. f. Anat. 1895.

columnar cells is covered internally by a delicate basement-membrane, the *limitans ciliaris*, which sends offsets between the cells.[1]

The double layer of cells is continued, as before said, over and between the ciliary processes to join the uveal layer upon the posterior surface of the iris (*pars iridica retinæ*). On the ciliary processes, and especially their anterior aspect, glandular depressions of the epithelium occur, which may be solid or may be provided with a lumen like true tubular glands (E. T. Collins). The function of these *ciliary glands* is not certainly known, but they are believed to take part in the secretion of the aqueous humour (see p. 211).

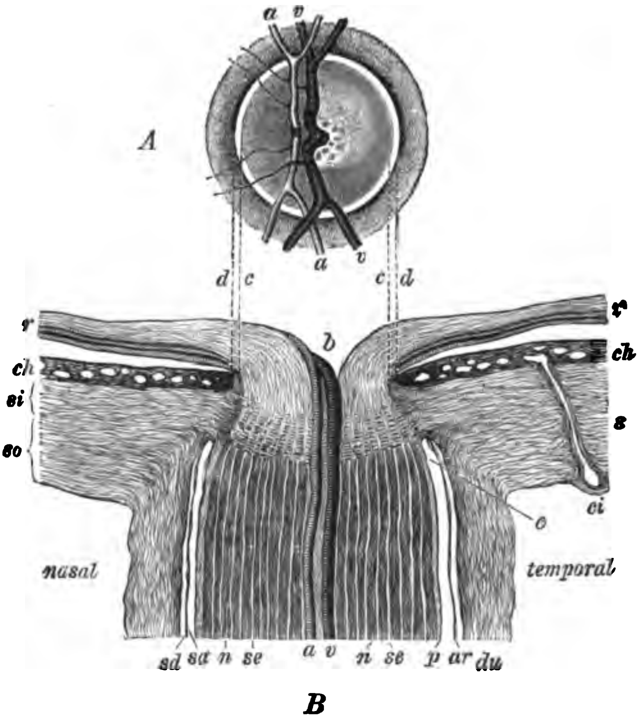

FIG. 180.—SECTION THROUGH THE PLACE OF ENTRANCE OF THE OPTIC NERVE (B), TOGETHER WITH THE OPHTHALMOSCOPIC VIEW OF THE DISC (A), TO SHOW THE CORRESPONDING PARTS OF THE TWO. (Fuchs, after Jaeger.)

c, *d*, lines of correspondence; *b*, depression in centre of disc; *r*, retina; *ch*, choroid; *si*, *so*, inner and outer parts of the sclerotic coat, *s*; *ci*, a ciliary artery cut longitudinally; *a*, *v*, central artery and vein; *sd*, subdural space; *sa*, subarachnoid space; *du*, dural sheath; *ar*, arachnoidal sheath of nerve; *p*, pial sheath; *n*, nerve-bundles; *se*, septa between them

Vessels of the retina.—A single artery (*arteria centralis retinæ*), a branch of the ophthalmic, passes between the bundles of fibres of the optic nerve to the inner surface of the retina at the middle of the papilla optici (fig. 180). It enters the nerve with a prolongation of the pial sheath, about 10–20 mm. from the globe of the eye, being accompanied by the corresponding vein, which is one-third to one-fourth larger than the artery; both give off small branches to supply the central part of the nerve. Emerging at the papilla oculi the central vessels divide into branches (fig. 180, A; fig. 162), usually two—one above, the other below (*superior and inferior papillary branches*)—each of these again almost immediately—*i.e.* on the papilla itself, but occasionally within the nerve before emerging at the papilla—dividing into two branches which arch out towards the sides (*superior and inferior nasal and temporal branches*); the temporal are somewhat the larger, and as they bend round the macula lutea they send numerous fine branches into it which end, a short distance from the centre of the fovea, in capillary loops (fig. 181). The macula is also supplied by small vessels which pass directly to it from the papilla. The middle of the fovea centralis has no blood-vessels. The main branches of the vessels pass forwards in the nerve-fibre layer, close to the limitans interna; the smaller branches lie at the boundary of the ganglionic layer. They divide dichotomously as they proceed, and give off fine offsets to the substance of the retina, where they form two capillary networks, the one in the nerve and ganglionic layer, the other in the inner nuclear layer. The capillaries of the former are mainly connected with the arteries, and those of the latter with the veins, the communication between the two networks being effected by vertically and obliquely coursing capillaries which traverse the inner molecular layer. In the macula lutea the ganglionic layer is especially vascular. No vessels, as a rule, penetrate the outer molecular layer (His, Hesse), so that the outer retinal layers

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[1] According to Metzner (Verhandl. d. Naturf.-Ges. Basel, xvi. 1903), there are narrow cells between the columnar elements which are continued into fibres of the zonule of Zinn (see p. 256).

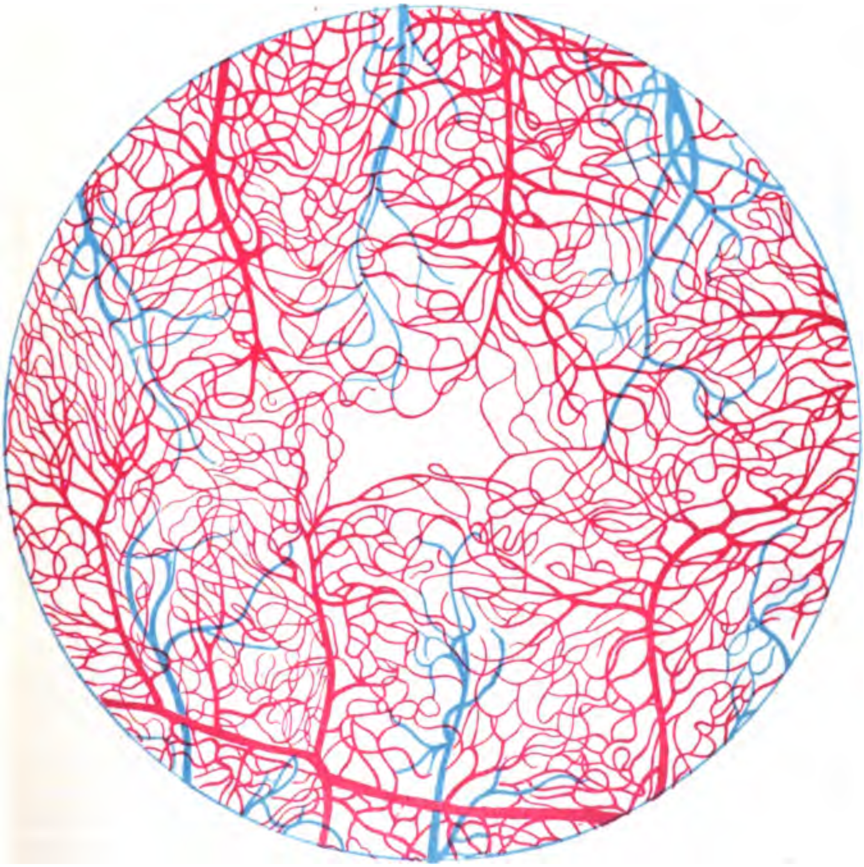

FIG. 181.—BLOOD-VESSELS OF THE RETINA IN THE REGION OF THE MACULA LUTEA. Magnified 50 diameters. (From Leber, after a figure by O. Becker; preparation by H. Müller.)

are entirely destitute of blood-vessels. The retinal arteries have no anastomoses, thus resembling those of the grey matter of the brain.

The *vena centralis retinæ*, which accompanies the artery and carries blood away from the retina, usually passes directly into the cavernous sinus, but sometimes into the superior or inferior ophthalmic veins. The retinal veins show no anastomoses. Towards the ora serrata they tend to bend round in a circular manner, but without intercommunication (Langenbacher).

The vascular system of the retina is nowhere in direct communication with the choroidal vessels. Near the entrance of the optic nerve, however, it comes into communication with some offsets from the posterior ciliary in the sclerotic coat, and the choroidal vessels also send branches to join the long-meshed network in the optic nerve furnished by the central artery. These occasionally penetrate to the papilla optici, where they may be detected with the ophthalmoscope (H. Müller; Nettleship) (*cilio-retinal vessels*). The arteries of the retina have the usual coats, but the veins resemble capillaries in structure, their walls consisting of a single layer of endothelial cells without any muscular tissue. Outside the endothelial layer is a space (perivascular lymphatic space, His) both in the veins and capillaries, bounded externally by a second endothelial layer (forming the wall of the lymphatic space). Outside this again is found, in the case of the veins, a layer composed of a peculiar retiform tissue. These perivascular lymphatic spaces are in communication with the lymphatic spaces of the optic nerve, and may be filled by injecting coloured fluid under the sheath which that nerve derives from the pia mater. Other lymph-spaces also become injected by the same process—viz. the interstices between the nerve-bundles which radiate from the papilla optici, the capillary space between the limitans interna and the hyaloid membrane of the vitreous humour, and finally even the irregular interstice between the pigmentary layer and the layer of rods and cones (Schwalbe). With one or two exceptions (Chelonia, eel) no vertebrates below mammals have blood-vessels in the retina; even in some mammals the distribution is restricted to the posterior part of the eye and to the nerve-fibre layer.[1]

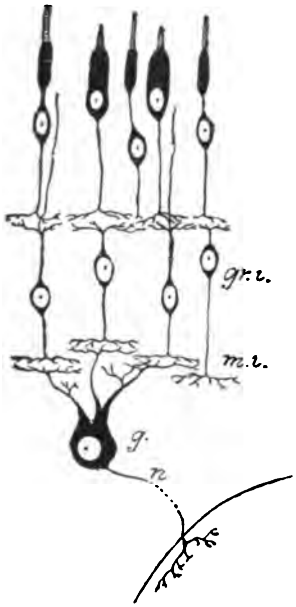

FIG. 182.—DIAGRAM SHOWING THE MODE OF CONCATENATION OF THE VISUAL NERVOUS ELEMENTS IN THE VERTEBRATE TYPE. (After G. Retzius.)

In the fœtus the arteria centralis retinæ is prolonged forwards through the vitreous humour as the *arteria hyaloidea*, which runs in the canal of Stilling (see p. 254) to the posterior surface of the lens, when it is distributed over the capsule (*arteria capsularis*). From the hyaloid artery branches grow into the vitreous humour. They anastomose freely in this, forming an arterial *rete mirabile*. Anteriorly they join the vessels of the lens capsule, which also receives vessels from the ciliary system. There is no vein corresponding to the hyaloid artery; the blood which it conveys passes at the pupillary margin into the veins of the iris and through these into the choroidal veins (Leber). The actual retinal vessels are somewhat late in development, and grow from the entrance of the arteria hyaloidea gradually over the inner surface of the retina, forming the *membrana vasculosa retinæ.* This reaches the ora serrata between the third and sixth months, but at the sixth month the retina itself is still non-vascular. After this time vessels begin to grow into the retina.

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[1] On the distribution of the retinal vessels, see H. Müller, Zeitschr. f. wiss. Zool. viii. 1856; Arch. f. Ophth. ii. 1856, and iv. 1858, Würzb. naturwiss. Zeitung ii. 1862; Leber, Arch. f. Ophth. xviii. 1872, and xxvi. 1880; Magnus, Habilitationschrift, Leipzig, 1873; Nettleship, Ophth. Hosp. Rep. viii. 1875, ix. 1877; H. Virchow, Würzb. Sitzungsb. 1879; Hesse, Arch. f. Anat. (u. Physiol.) 1880; W. His, *ibid.*; Langenbacher, Vierteljahrschr. f. Veterinärkunde liii. 1880; Denissenko, Arch. f. mikr. Anat. xviii. 1880; *ibid.* xix. and xxi. 1881; Ayres, Arch. of Ophth. xi. 1882; Barrett, Journ. Physiol. vii. 1886; Lang and Barrett, Ophth. Hosp. Rep. xii. 1888; Musgrove, Journ. Anat. and Phys. 1892; O. Schultze, Kölliker's Festschrift, 1892; Voll, *ibid.*; G. Lindsay Johnson, Phil. Trans. 1901. See also Leber, 'Die Cirkulationsverhältnisse des Auges' in Graefe-Saemisch, Handb. d. Augenheilk. 1903, where a full bibliography of the subject is given.

Interconnexion of the retinal elements.—It is only comparatively recently, by the aid of the method of Ehrlich (staining *intra vitam* with methylene-blue) and that of Golgi (chromate of silver impregnation), that histologists have been able definitely to trace the course and connexions of the fibres which pass from and to the several retinal elements. The most fruitful applications of Golgi's method have been made by Cajal, following up investigations by Dogiel, which were made by Ehrlich's method; it is the account given by the first-named observer which will here in the main be followed.

In the first place, it would appear that there is no direct anatomical continuity between the elements of the several layers, with the exception of the nerve-fibres of the first layer and the ganglionic cells immediately external to them. As with other parts of the nervous system, the nerve-elements of the retina are anatomically isolated units, merely coming into connexion with one another by interlacement and contact of their arborescent processes (figs. 182, 183). These interlacements occur in two places—viz. in the two molecular layers. In the outer molecular layer is found the interlacement by which the rod- and cone-elements are brought into connexion with the inner granules. In the inner molecular layer there is a series of interlacements running mainly in planes parallel to the surfaces of the layer, and serving to bring the elements of the inner nuclear layers into connexion with those of the ganglionic layer. Finally, some of the nerve-fibres of the innermost layer are not connected with the ganglion-cells, but ramify directly in the molecular layer or pass through this layer and ramify among the inner granules (fig. 183).

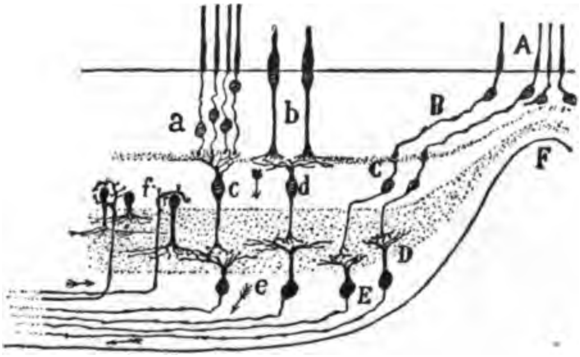

FIG. 183.—INTERCONNEXION OF RETINAL ELEMENTS. (Cajal.)

F, fovea; A, cones at fovea; B, cone-fibres; C, bipolars; D, E, ganglion-cells; *a*, rod-elements, and, *b*, cone-elements outside fovea; *c*, rod-bipolar; *d*, cone-bipolar; *e*, ganglion-cells; *f*, centrifugally conducting fibres.

The retina, therefore, is essentially formed by a number of nerve-cell or neurone chains, the elements of which are arranged in three series from without in. The first of these is formed by the rod- or cone-element. One end of this element abuts against or is imbedded in a pigment-cell, the other end interlaces by the terminal arborisation of the rod- or cone-fibre within the outer molecular layer, with the peripheral arborisations of the next elements. The latter are the bipolar inner granules (fig. 182, *gr.i.*). These, by the peripheral process just mentioned, interlock with the arborisations of the rod- and cone-fibres and in some animals also send the fibres of Landolt as far as the membrana limitans externa. By their central processes they ramify within the inner molecular layer (*m.i.*) and interlace with the peripheral processes of the ganglion-cells (*g*). The last-named form the third of the concatenated elements. Their peripheral processes spread out in the inner molecular layer, and are connected with the central processes of the inner granules in the manner just stated. Their central process (*n*) is an axis-cylinder of one of the fibres of the optic nerve, and its terminal ramification is to be found in the grey matter of the superior corpora quadrigemina, or of the lateral geniculate bodies. The functions of the other cell-elements in the retina, such as the horizontal cells, which ramify in the outer molecular layer, and the amacrine cells of Cajal, which are distributed in the inner molecular layer, are still obscure.

Although it is convenient from the morphological point of view to look upon the rod- and cone-elements as of the nature of sensory bipolar nerve-cells, the axons of which are represented by the rod- or cone-fibres, it must be pointed out that in certain particulars they exhibit differences from axons, especially in the fact that they do not stain *intra vitam* with methylene-blue (Dogiel) and that they are doubly refractile, which is not the case with nerve-axons. Moreover, they are not the first process of the cell to sprout out from the cell-body, as invariably happens with the axons of developing nerve-cells.

HISTOGENESIS OF THE RETINA.[1]

The retina is developed as a protrusion from the fore-brain, which becomes doubled-in and is at first formed entirely of two layers of the neural ectoderm. One of these becomes the pigmented epithelium; from the second all the other retinal strata are developed.

As with the ectoderm of the neural canal, the cells of the embryonic retina become at an early period differentiated into *external* or *germinal cells*, which are in constant process of multiplication, and *internal cells* or *neuroblasts*, which occupy the deeper strata (those farthest from the original cavity of the optic vesicle) and develop into nerve-cells and neuroglia-elements (including the fibres of Müller). The first cells to show differentiation are the *ganglion-cells*. From them an axon begins to sprout out, and these grow along the internal surface of the embryonic retina and converge to the papilla, and then proceed along the optic stalk to form the *fibres of the optic nerve*. But long before they have proceeded thus far, dendrons make their appearance from the same cells and, ramifying horizontally, constitute the bulk of the commencing *internal plexiform layer*. At about the same time the *amacrine cells* show differentiation and take part in the formation of the same layer. This change is found in the recently born kitten. At this time all the remaining elements of the retina appear either as monopolar or as bipolar cells, not easily distinguishable from one another, the monopolar form apparently in all preceding the bipolar. Some of these elements are developed into the visual cells, others into the bipolars and horizontal cells, and others into the cells of Müller.

The *visual cells* (rod- and cone-elements) are at first monopolar with the single process directed peripherally. This shows no sign of the future rod or cone, and extends only as far as the future limitans externa. Presently the rod- or cone-fibre grows out from the opposite pole and ends in an irregular enlargement at the level of the future external plexiform layer, where the *horizontal cells* are now becoming differentiated. The rods and cones themselves are much later in appearing; they are not formed in the kitten or puppy at birth, but begin to show soon after, growing gradually beyond the limitans.

The *bipolars* are at first monopolar, and are intermingled with the visual cells, their processes extending to the future limitans externa. By the fourth day after birth in the dog and cat a second process is well marked, and extends to the internal plexiform layer. Later the peripheral process is withdrawn, in mammals, from the limitans externa to the external plexiform layer, but in lower vertebrates it remains as the fibre of Landolt.

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[1] For further details, see Cajal, Testura del sistema nervioso, 1899.

THE VITREOUS BODY.

The vitreous body occupies the greater portion of the eyeball. It is quite pellucid in aspect, and of a soft gelatinous consistence. Sub-globular in form, it fills about four-fifths of the ball, and serves as a support for the delicate retina; but it may be readily separated from the latter, except behind, at the entrance of the optic nerve, where the connexion is closer, the retinal vessels having here entered it in fœtal life. At the fore-part it is hollowed out (*fossa patellaris*) for the reception of the lens and its capsule, to which it is closely adherent. The vitreous humour contains 98·5 per cent. of water. It weighs 7–8 grammes, and has a specific gravity of about 1·005. The solids are chiefly salts and extractives, with a trace of protein and nucleo-protein. The fluid is probably secreted, like that of the anterior chamber, by the ciliary processes and their glands.

The surface of the vitreous humour is covered everywhere by a thin glassy membrane, named *hyaloid*, which lies between it and the retina. It has been stated by more than one modern observer that there is no limiting membrane between the vitreous humour and the lens-capsule, but it has been shown by Anderson Stuart that the older view regarding this subject is more correct, for after removal of the lens within its capsule it is still possible to demonstrate the existence of a delicate membrane over the *fossa patellaris* in the front of the vitreous humour, which he regards as a continuation of part of the hyaloid membrane. This membrane, as well as the zonule of Zinn, is, however, quite permeable to fluids (Schwalbe, Priestley Smith), and according to Retzius is merely a condensation of the fibrillar vitreous substance.

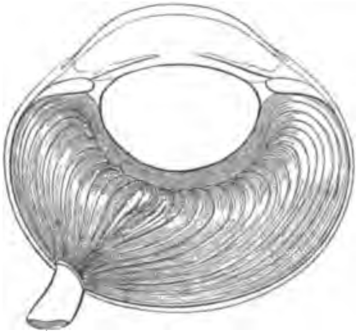

FIG. 184.—HORIZONTAL SECTION OF THE HORSE'S EYE HARDENED IN CHROMIC ACID. (After Hannover.)

The vitreous humour appears concentrically and meridionally striated throughout its whole depth.

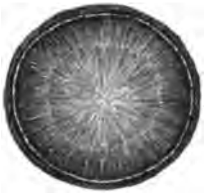

FIG. 185.—TRANSVERSE SECTION OF HUMAN EYE HARDENED IN CHROMIC ACID, SHOWING RADIAL STRIATION OF THE VITREOUS BODY. (After Hannover.)

No vessels enter the vitreous humour in the adult; its nutrition must therefore be dependent on the surrounding vascular structures—viz. the retina and the ciliary processes.

Although in the fresh state apparently structureless, or at least presenting under the microscope but faint traces of fibres and a few cells—the so-called corpuscles of the vitreous humour, to which we shall immediately refer—yet in preparations hardened in weak chromic acid, or acted upon in certain other ways, it is possible to make out a more or less distinct lamellation of the vitreous body, especially in its peripheral part—that, namely, nearest the retina; which part in the human eye has a somewhat firmer consistence than the more central portion. From the appearances (fig. 184) which have been obtained by such modes of preparation it has been conjectured by various observers that at least in this part the vitreous substance is divided into compartments by a number of delicate membranes arranged concentrically and parallel to the surface; although the actual existence of such membranous partitions has not been demonstrated. In addition to the above-mentioned concentric striation, a radial marking (Hannover) has also been observed in sections of vitreous humour made transversely to the axis of the eyeball (fig. 185), but whether there is any pre-existent structure to account for this appearance is also uncertain. It is conceivable that both appearances may be produced by the manner in which the albuminous substance has undergone coagulation by the reagent employed. That, however, the vitreous substance does in some way consist of a firmer material, enclosing in its meshes the more fluid portion, is shown by the fact that if either the whole or a piece of the vitreous humour be thrown upon a filter a small proportion always remains upon the latter; although by far the larger part drains away, and may be collected as a clear watery fluid.

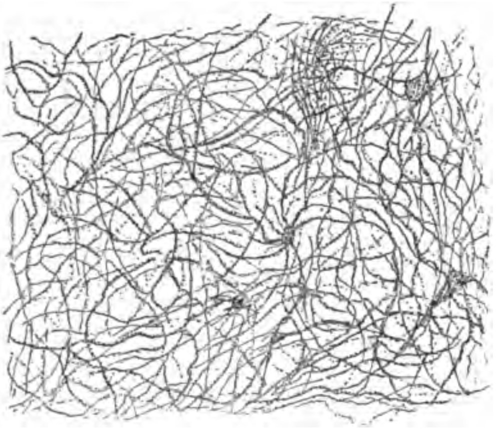

FIG. 186.—FIBRES OF VITREOUS; A FEW CELL-REMNANTS ARE VISIBLE. Magnified 450 diameters. (G. Retzius.)

The existence of a reticulum of fibres throughout the vitreous, which has been affirmed by many authorities, appears to be established beyond a doubt by the investigations of Retzius. In the fœtal condition many of these fibres are seen to be processes of ramified cells, but in the adult most of the cell-bodies have disappeared, and nothing more than a feltwork of fibres, with here and there enlargements upon them which probably represent the atrophied cell-bodies, is visible (fig. 186).[1]

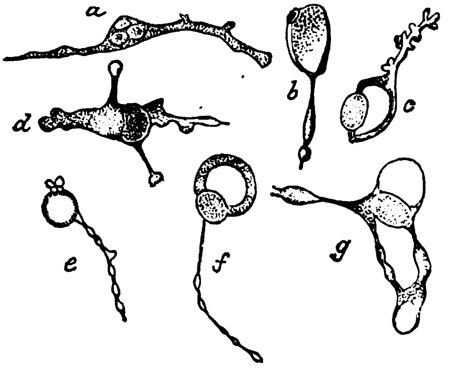

FIG. 187.—CELLS OF VITREOUS HUMOUR. (Schwalbe.)

a and *d*, without vacuoles; *b*, *c*, *e*, *f*, *g*, vacuolated.

It has also been shown by Iwanhoff, Younan, and A. Stuart that the periphery of the vitreous humour near the ciliary body is considerably strengthened and rendered more consistent by the presence of an accumulation of fibres which encircle this part of the posterior chamber of the eye, and are believed to aid in supporting the ciliary body and the attachment of the suspensory ligament of the lens to that body. The fibrous structure in question appears to be continuous with the fibres of the zonule of Zinn (see p. 256), which are here attached to the hyaloid membrane.

The fluid of the vitreous body, which closely resembles in composition that of the aqueous humour, appears to find exit partly by way of the canal of Stilling to the circumvascular lymph-spaces of the central vessels of the retina, and eventually to the subpial space surrounding the optic nerve, but chiefly around the margin of the lens into the anterior chamber of the eye,[2] and then partly into the spaces of

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[1] G. Retzius, Biol. Unters. vi. 1894. Wolfrum (Arch. f. Ophth. 1906) considers all the fibres of the vitreous to be of ectodermic origin. But although it seems clear (see fig. 188) that the place of the vitreous is occupied by a network of fibres previous to the appearance of mesenchyme-cells within it, it is not equally certain that these represent the fibrils of the future vitreous, which are more probably of mesenchyme origin.

[2] Priestley Smith, Ophthalmic Review, 1888.

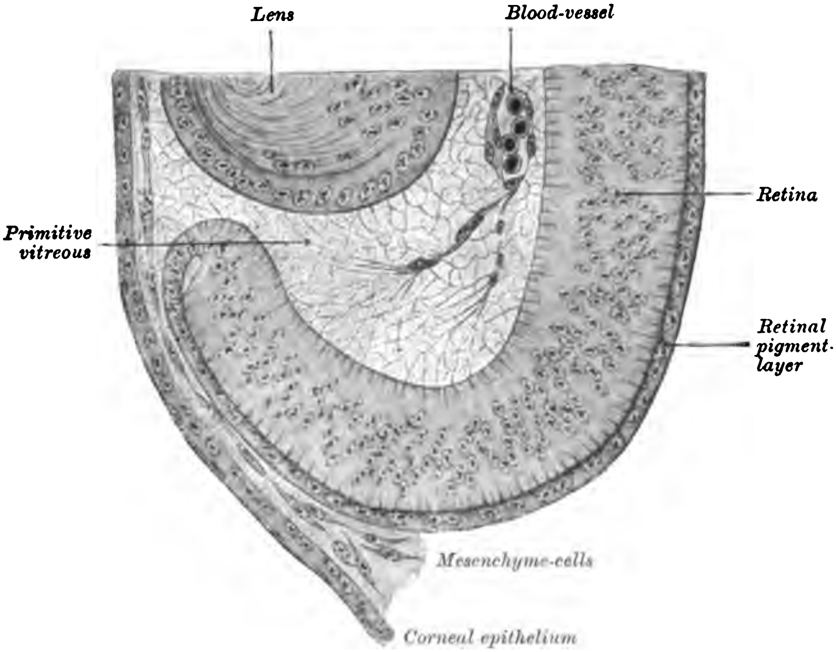
Lens
Blood-vessel
Retina
Primitive vitreous
Retinal pigment-layer
Mesenchyme-cells
Corneal epithelium

FIG. 188.—SECTION OF DEVELOPING EYE OF TROUT-EMBRYO. (Szily.)

The vitreous is composed of a network of fibres, which make their appearance before any mesenchyme-elements are seen within it. These are, however, now beginning to enter along with the blood-vessel which runs in the canal of Stilling.

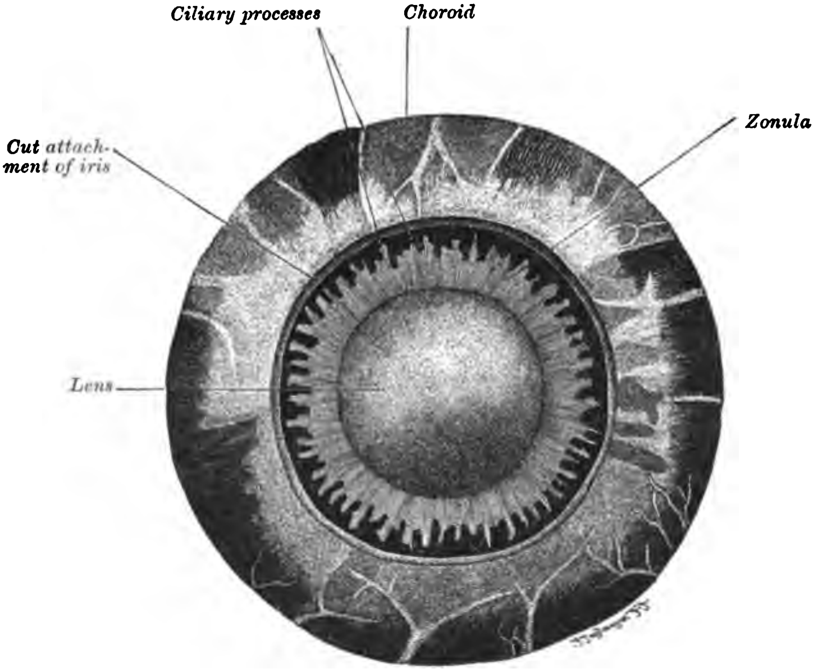
Ciliary processes
Choroid
Zonula
Cut attachment of iris
Lens

FIG. 189.—LENS WITH ZONULE AND CILIARY PROCESSES AS SEEN FROM THE ANTERIOR ASPECT AFTER CUTTING AWAY THE CORNEA, SCLEROTIC, AND IRIS. (O. Schultze.)

The lighter appearance of the choroid near the attachment of the iris is due to the ciliary muscle.

Fontana, partly through the anterior surface of the iris.[1] The fluid appears to be chiefly secreted by the posterior part of ciliary processes.

There further exists, nearly but not quite in the axis of the eye, a definite structure in the shape of a distinct canal, about 2 mm. in diameter, filled with fluid and extending from the *papilla optici* to the back of the lens-capsule, where it apparently terminates blindly in a slight enlargement (fig. 115). This is the *canalis hyaloideus* or *canal of Stilling*. It is best shown in the fresh eye, and may be also injected by forcing a coloured solution under the pia-matral sheath of the optic nerve (Schwalbe). The canal widens somewhat towards its posterior part; its wall is composed of an extremely delicate homogeneous membrane. It represents the place of passage of an offset from the central artery of the retina to the capsule of the lens in the fœtus, and along it lymph may pass behind into the lymphatic spaces of the optic nerve, and in front round the edge of the lens into the canal of Petit. Remains of the hyaloid artery are usually to be detected within it.

Scattered about throughout the substance of the vitreous humour are a variable number of corpuscles, for the most part possessed of amœboid movement. Some of these cells are remarkable for the very large vacuoles which they contain, and which distend the body of the corpuscle, pushing the nucleus to one side; the cell-processes are often peculiar in possessing numerous little secondary bud-like swellings, or they may present a varicose appearance, like strings of pearls (fig. 187).[2]

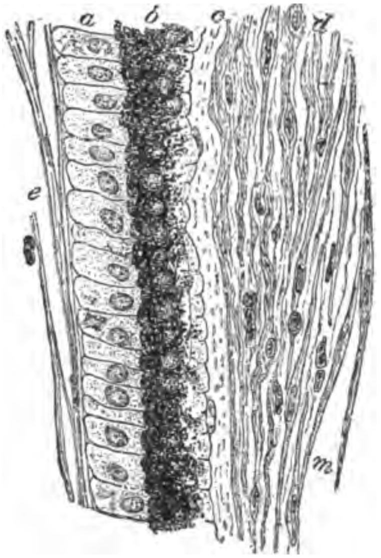

FIG. 190.—SECTION THROUGH THE CILIARY RING CLOSE BEHIND THE CILIARY PROCESSES. Magnified 335 diameters. (Piersol.)

a, *b*, the inner and outer layers of the pars ciliaris retinæ; *c*, the continuation of the membrana basilaris or membrane of Bruch; *d*, choroidal stroma containing muscle-cells (*m*) of the ciliary muscle; *e*, fibres of attachment of the suspensory ligament of the lens.

Suspensory apparatus of the lens.—The hyaloid membrane invests, as before mentioned, the whole of the vitreous humour. At the ora serrata it appears to split into two layers—one, which must be regarded as the hyaloid membrane proper, being that which has been already mentioned as demonstrable over the anterior surface of the vitreous humour, although doubts have been cast upon the real membranous character of this portion (see p. 253). The other layer into which the hyaloid appears to split adheres to the pars ciliaris retinæ so closely that when removed it generally shows some of the cells of that structure clinging to its outer surface. This is the *limitans ciliaris* already alluded to. Attached to it is a fibrous structure firm in consistence, extending over the ciliary body inwards to be attached to the capsule of the lens, for which it forms a suspensory apparatus known as the *zonule of Zinn*, or *zonula ciliaris* (fig. 190, *c*). Its free part, which stretches from the ciliary body to the lens-capsule, is termed the *suspensory ligament of the lens* (figs. 115, 191). The hyaloid membrane, into which it passes posteriorly, is exceedingly thin and delicate, and readily thrown into folds when detached. Under the microscope this membrane presents no appearance of structure; but flattened against its inner surface are generally to be seen a number of corpuscles (leucocytes) which exhibit amœboid movements. The zonule, on the other hand, is composed of or at least contains radiating meridional fibres, stiff in appearance, but possessed of considerable elasticity; they commence opposite the ora serrata, and are firmly adherent here to the membrane covering the pars ciliaris retinæ. Over the ciliary body the adhesion of the zonule is firm to the elevations of that body (ciliary processes), but over the intervals between the ciliary processes the adhesion is less close, so that a series of pouches, narrowing posteriorly and widening anteriorly where they communicate with the posterior chamber, become left between zonule and ciliary body (*recesses of the posterior chamber*, Kuhnt). It is into these recesses that the ciliary glands (see p. 211) open. The recesses are occupied by aqueous humour, and traversed by some of the fibres belonging to the zonule of Zinn; they are also partly subdivided by small subsidiary folds of the ciliary body which project into the recesses. Opposite the most prominent part of the ciliary processes the zonule gives off bundles of fibres which pass meridionally inwards towards the margin of the lens, some reaching and extending a short distance over its anterior surface, others just reaching its posterior surface, and

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[1] Nuël and Benoit, Arch. d'Ophth. xx. 1899.

[2] See on the structure and development of the vitreous body, H. Virchow in Anat. Ergebn. 1900; also on the development, Szily, Anat. Anz. xxiv. 1903. On the cells of the vitreous, Younan, in Journ. Anat. and Physiol., 1885.

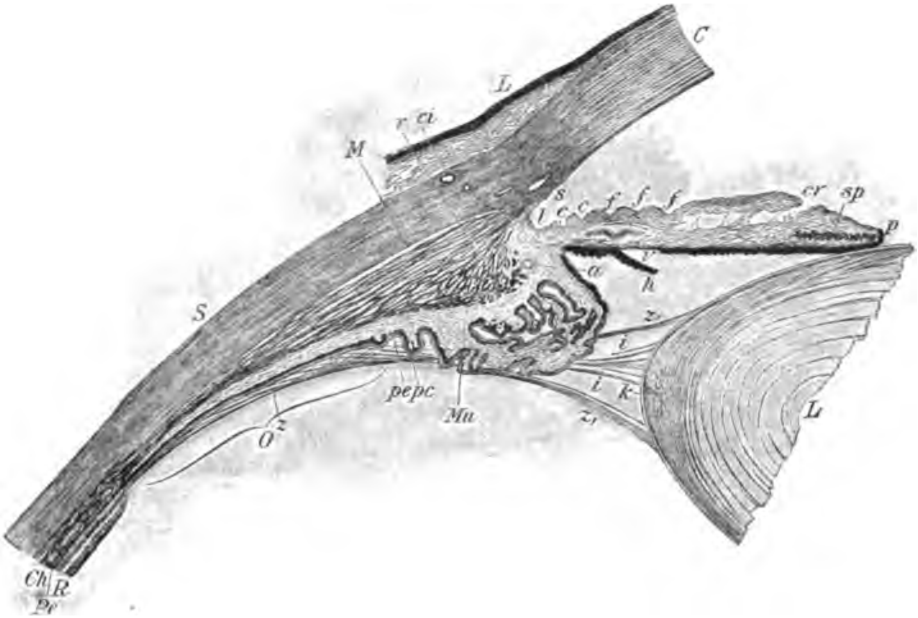

FIG. 191.—SECTION THROUGH THE CILIARY PART OF THE EYE, INCLUDING PART OF THE CORNEA, THE ORA SERRATA, THE IRIS, AND THE EDGE OF THE LENS WITH ITS SUSPENSORY LIGAMENT. Magnified. (From Fuchs.)

C, cornea; *S*, sclera; *Ch*, choroidea; *R*, retina; *Pe*, its pigmented epithelium; *O*, pars ciliaris retinæ: this is continued over the ciliary processes; *pe*, *pc*, pigmented and non-pigmented cells of pars ciliaris; *L*, lens; *M*, points to, but does not quite reach the ciliary muscle (meridional fibres); *r*, its radiating fibres; *Mu*, circular (Müllerian) fibres; *ci*, anterior ciliary artery; *s*, canal of Schlemm; *c*, *c*, *f*, *f*, folds and depressions in anterior surface of iris; *cr*, a crevice in this surface (? artificial); *sp*, sphincter pupillæ; *p*, edge of pupil; *h*, pigment behind iris (pars iridica retinæ), detached at *v*; *a*, blood-vessel; *z*, zonule of Zinn; *z'*, *z'*, its continuation on the suspensory ligament; *i*, *i*, spaces between the fibres of the suspensory ligament; *k*, capsule of lens.

others again occupying intermediate positions at the margin (fig. 191). They are all firmly cemented to the lens-capsule. Those which pass anteriorly originate mainly from the part of the zonule which lies in the intervals between the ciliary processes; they form a radially fibrous membranous layer; but it is not quite complete, for coloured injection can be easily made to pass from the interstices between the lens-capsule and the ciliary body into the aqueous humour, and *vice versâ*. The clefts in it are fine enough, however, to retain air if blown into this interstice; if this be done after removal of the whole vitreous body (a removal which can be easily effected in an eye which has been left for a day or two at the ordinary atmospheric temperature), the interstices which correspond with the eminences of the ciliary processes are most distended, and the appearance of a sacculated canal (*canal of Petit*), encircling the lens, is seen.[1]

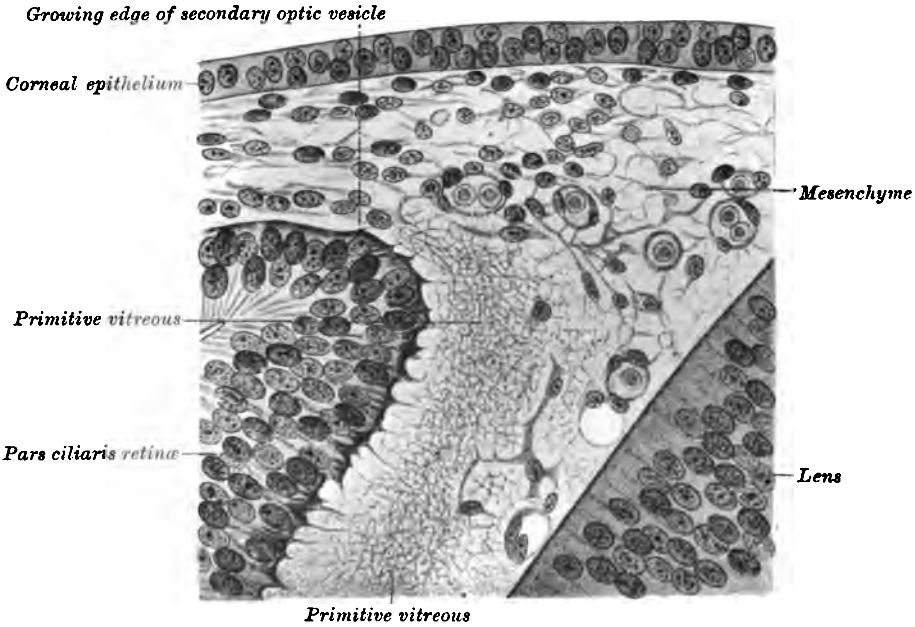

FIG. 192.—FROM SECTION OF EYE OF EMBRYO CALF, 15 MM. LONG, SHOWING FIBRES IN PRIMITIVE VITREOUS CONTINUOUS WITH PROCESSES OF CELLS OF PRIMITIVE RETINA. Magnified 560 diameters. (Kölliker.)

The canal which is thus artificially produced is bounded behind by the membranous layer which covers the front of the vitreous humour, and in front by the imperfect membrane above alluded to as formed by the fibres of the zonule which are passing to the anterior surface of the lens-margin. Since these fibres spring most abundantly from the part of the zonule which is opposite the intervals between the ciliary processes, the membrane is as it were tied down at those intervals and can only be distended between them; hence the sacculated aspect of the so-called canal.

According to Schoen[2] the fibres of the zonule are originally continuous with the Müllerian fibres of the ora serrata, and are therefore of ectodermic origin. Metzner states that the zonule-fibres are developed within special sustentacular cells which lie among the inner or pigment-free cells of the pars ciliaris retinæ, and that the fibres extend from these cells, on the one hand through the zonule to the lens-capsule, and on the other hand through the pigment-layer to the membrana basilaris of the choroid.

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[1] See, on the canal of Petit, Aeby, Arch. f. Ophth. xxviii. 1882; Cleland, Memoirs and memoranda in Anatomy; F. Haase, Inaug. Diss., Rostock, 1899.

[2] Arch. f. Ophth. xxxii. 1886; Anat. Anzeiger x. 1895. See also Kölliker, Zeitschr. f. wiss. Zool. lxxvi. 1904; Wolfrum, *op. cit.*, and Sugamma (abstr. in Schwalbe's Jahresb. f. Anat. 1907).

As just stated, in addition to this anterior membranous prolongation of the zonule, other fibres, more scattered in their disposition, pass at intervals across to the periphery of the lens, some being attached to the extreme edge, others coming into continuity with the posterior capsule, and others again occupying intermediate positions (fig. 191). Those which pass to the posterior surface of the lens-capsule and to the extreme edge of the lens come for the most part from the part of the zonule which overlies and is adherent to the most prominent portion of the ciliary body, and these fibres therefore partially cross in direction those which are coming from the depressions and are passing to the anterior surface.[1]

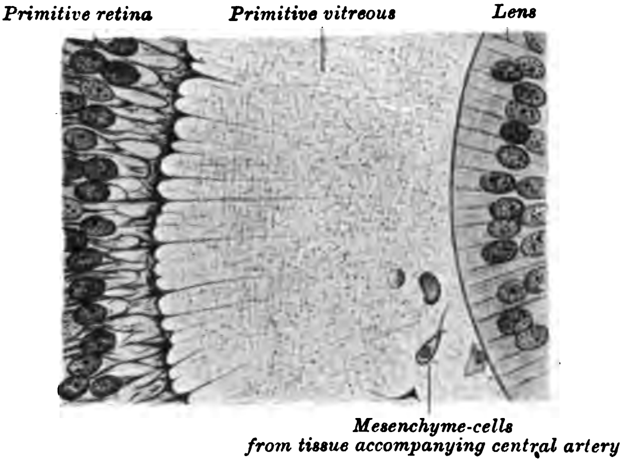

FIG. 193.—PART OF THE PREPARATION SHOWN IN FIG. 192, BUT FURTHER BACK, SHOWING THE FIBRES WHICH FORM THE ZONULE EXTENDING FROM CELLS OF THE PRIMITIVE RETINA INTO THE PRIMITIVE VITREOUS. Magnified 560 diameters. (Kölliker.)

THE LENS.

The lens (*lens crystallina*) is a transparent solid body, of a doubly convex shape, with the circumference rounded off. It weighs about 0·25 grammes and has a specific gravity of 1·1. It is completely enclosed by a transparent, highly elastic membrane, known as the *capsule of the lens*. The anterior surface is in contact with the aqueous humour except near the pupil, where the iris rests upon it; the posterior is imbedded in the vitreous humour. Around the circumference is the zonule. The capsule is strongest anteriorly (anterior capsule) and thinnest over the posterior surface of the lens (posterior capsule). Chemically the lens-capsule yields neither elastin nor gelatin, but appears similar in composition to the sarcolemma of muscle and the membranæ propriæ of glands. An indistinct fibrous and lamellar structure has been described in it. The convexity of the lens is not alike on the two surfaces, being greater behind; moreover, the curvature is less at the centre than towards the margin. When in its natural position it measures 8 mm. to 9 mm. across, and 3·6 mm. to 4 mm. from before backwards, according to the condition of accommodation. The distance of its anterior surface from the posterior surface of the cornea is between 2 mm. and 3 mm.; of its posterior surface from the retina, between 15 mm. and 16 mm. The radius of curvature during life of the anterior surface varies with the condition of accommodation from about 10 mm. when the eye is accommodated for distant vision, to 6 mm. when accommodated to the near-point of distinct vision (Helmholtz). That of the posterior surface is about 6 mm. in distant vision and 5 mm. or 5·5 mm. in near vision. In a fresh lens, divested of its capsule, the outer portion is soft and easily detached; the succeeding layers are of a firmer consistence; in the centre the substance becomes much harder, constituting the so-called 'nucleus.' The refractive index of the outer portion is 1·39; of the central part, 1·41. Its focal length is about 55 mm., and its refractive power about 25 diopters.[1] On the anterior and posterior surfaces are faint white lines directed from the poles towards the equator; these in the adult are somewhat variable and numerous on the surfaces (fig. 194), but in the fœtal lens throughout, and towards the centre of the lens in the adult, they are three in number, diverging from each other like rays at equal angles of 120° (fig. 195). The diverging lines have an alternating position on the two surfaces. Thus, of those seen on the posterior surface of the fœtal lens, the upper one is vertical, and the two lower are oblique; whereas, of those

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[1] For the arrangement of the zonule-fibres and suspensory ligament, see G. Retzius in Tigerstedt's Physiology, vol. ii. See also, for a fuller discussion of the structure of the zonule, G. A. Piersol's article on the 'Microscopical Anatomy of the Eyeball,' in Norris and Oliver, System of Diseases of the Eye, 1897.

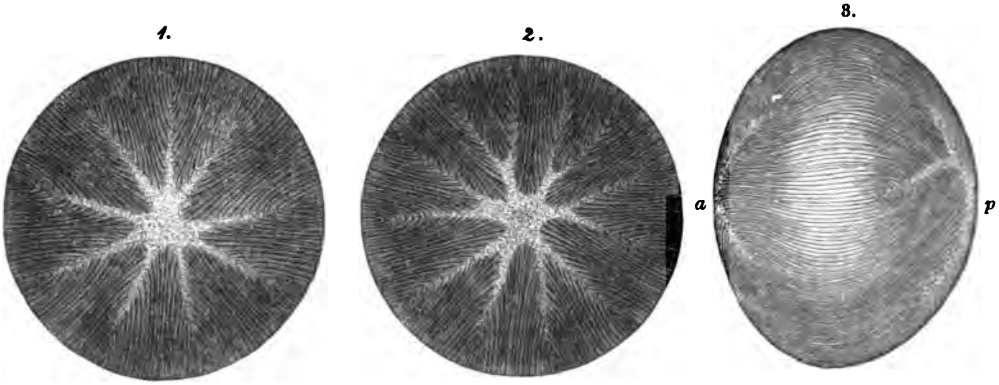

FIG. 194.—1, FRONT VIEW; 2, HIND VIEW; 3, LATERAL VIEW OF THE FIBROUS STRUCTURE OF THE ADULT LENS. $\frac{5}{1}$. (After Arnold.)

In 3, *a*, anterior; *p*, posterior pole. The direction of the superficial fibres is indicated by the curved lines.

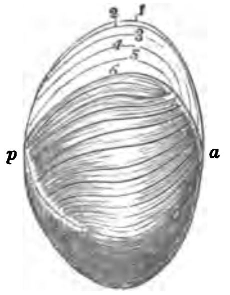

FIG. 195.—DIAGRAM TO ILLUSTRATE THE COURSE OF THE FIBRES IN THE FŒTAL CRYSTALLINE LENS. (Allen Thomson.)

a, anterior; *p*, posterior pole.

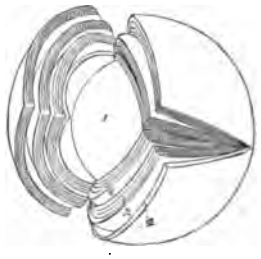

FIG. 196.—LAMINATED STRUCTURE OF THE CRYSTALLINE LENS, SHOWN AFTER HARDENING IN ALCOHOL. $\frac{4}{1}$. (Arnold.)

1, nucleus; 2, 2, lamellæ.

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[1] Hess, in Graefe and Saemisch, 2nd edition.

on the anterior surface the lower one is vertical and the upper two are oblique. These lines are the edges of planes or septa within the lens, diverging from the axis, and receiving the ends of the lens-fibres, which here abut against one another. They may be seen, by the aid of the ophthalmoscope, even during life (Tweedy). The rays seldom meet at a point in the centre of the surface, but usually along a somewhat irregular area.[1]

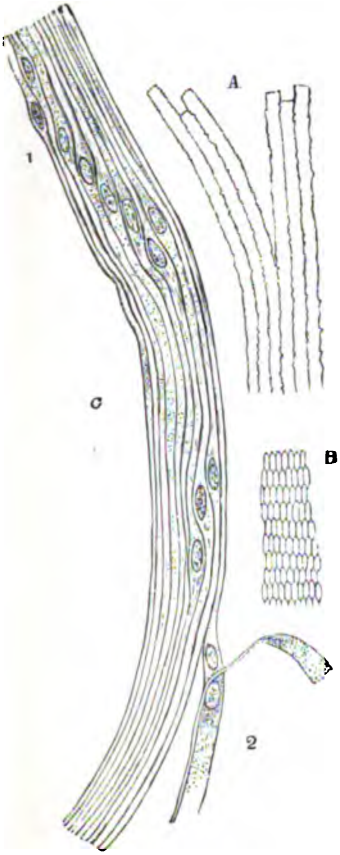

FIG. 197.—FIBRES OF THE CRYSTALLINE LENS. 350 diameters.

A, longitudinal view of the fibres of the lens from the ox, showing the serrated edges. B, transverse section of the fibres of the lens from the human eye (from Kölliker). C, longitudinal view of a few of the fibres from the equatorial region of the human lens (from Henle). Most of the fibres in C are seen edgeways, and, towards 1, present the swellings and nuclei of the 'nuclear zone'; at 2, the flattened sides of two fibres are seen.

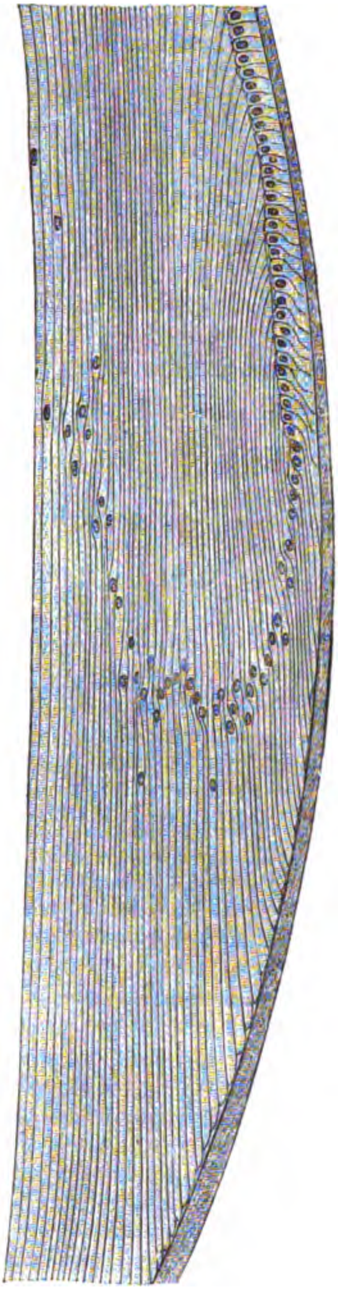

FIG. 198.—SECTION THROUGH THE MARGIN OF THE LENS, SHOWING THE TRANSITION OF THE EPITHELIUM INTO THE LENS-FIBRES. (Babuchin.)

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[1] Cf. Friedenburg, Arch. f. Augenh. xxxi. 1895. On the microscopic structure of the lens, see O. Schultze, in Graefe-Saemisch, 2nd edition, 1899

Structure.—When the lens has been hardened and the capsule removed, it is possible to artificially separate its superficial portion into a succession of concentric laminæ like the coats of an onion. They are not continuous, but separate into parts opposite the radiating lines above described (fig. 196). The laminæ, on the other hand, are themselves composed of long, riband-shaped, microscopic fibres, 0·005 mm. broad, which adhere together by their edges, the latter being often finely serrated (fig. 197, A). The minute serrations of adjacent fibres abut against one another so as to leave, as in other epithelial structures, fine interfibrillar or intercellular channels for the passage of fluid. The lens-fibres may be distinguished into three groups—viz. (1) those which form the central part or nucleus; (2) an intermediate group of fibres; and (3) the main mass of fibres which form the peripheral part of the lens.

The fibres of the central part have retained no special recognisable arrangement, but those of the intermediate group and those of the main mass are disposed in radial lines which are well seen in a section across the long axis of the fibres. The number of these radial lamellæ increases with the growth of the lens; thus Rabl found 1474 in the lens of a three-year-old child, but 2111 and 2258 respectively in two adult lenses. The lens-fibres pass in a curved direction from the intersecting planes of the anterior half of the lens to those of the posterior half, or *vice versâ*: in this course no fibre passes from one pole to the other, but those fibres which begin near the pole or centre of one surface terminate near the marginal part of a plane on the opposite surface, and conversely; the intervening fibres passing to their corresponding places between. The arrangement will be better understood by a reference to fig. 195, where the course of the fibres in the fœtal lens is diagrammatically indicated.

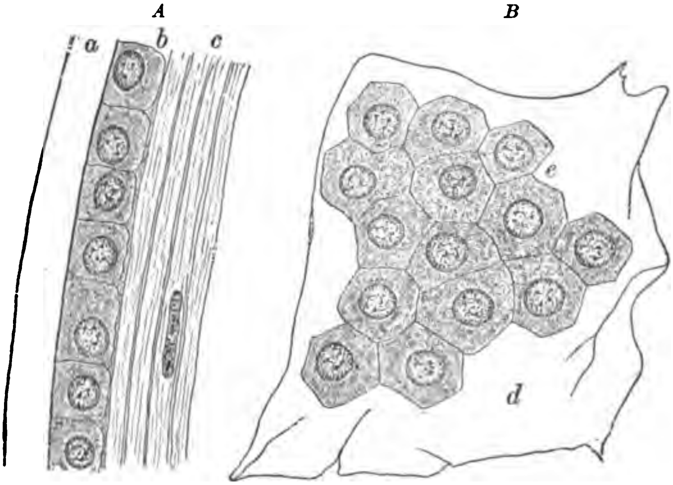

FIG. 199.—CAPSULE AND ANTERIOR EPITHELIUM OF LENS. Magnified 500 diameters. (Piersol.)

A, section of crystalline lens embracing capsule (*a*), anterior epithelium (*b*), and most superficial fibres (*c*) of cortex. *B*, portion of lens-capsule (*d*) seen from the surface, with a number of anterior epithelial cells (*e*) still adherent.

The lens-fibres, as the history of their development shows, are to be looked upon as greatly elongated cells. In the young state each has a clear oval nucleus, but in the fully formed lens the nuclei have disappeared from the fibres which form the more internal parts of the lens, and only remain in the more superficial layers. Here they are found not quite in the middle of each fibre, but slightly nearer the anterior end, their situation nearly corresponding in adjacent fibres, and they form by their juxtaposition the so-called ‘nuclear zone’ around the lens (fig. 197, C). The superficial fibres further differ from the more deeply seated ones in being softer and larger, and in possessing a plain, unserrated margin. The extremities of all the fibres are softer and more readily acted on by reagents than the middle parts, and the axial or more internal part of a fibre more so than the external, but the transition is gradual from one to the other, and there is no definite membrane enclosing each fibre. The lens-fibres when cut across are seen to be six-sided prisms (fig. 197, B). By reason of this shape they fit very exactly the one to the other, with but little inter-fibrillar cementing substance between. This is met with in rather larger quantity in the intersecting planes between the ends of the fibres.

The **capsule** of the lens is a transparent structureless membrane ; somewhat brittle and elastic in character, and when ruptured the edges roll outwards. The fore-part of the capsule, including the whole of the equatorial region, where the suspensory ligament joins it, is much thicker than the back : at the posterior pole of the lens the capsule is very thin indeed. In the adult, it, like the lens itself, is entirely non-vascular, but in the fœtus of man and mammals in general there is a network of vessels in the superficial part of the capsule, supplied by the terminal branch of the central artery of the retina, which passes from the optic papilla through the canal of Stilling in the vitreous humour to reach the back of the capsule, where it divides into radiating branches. After forming a fine network, these turn round the margin of the lens and extend forwards to become continuous with the vessels in the pupillary membrane and iris (fig. 153, p. 218).

Epithelium of the capsule.—At the back of the lens the fibres are directly in contact with the inner surface of the capsule, but in front they are separated from the latter by a single layer of cubical, polygonal, nucleated cells, which covers the whole anterior surface underneath the capsule (fig. 199). Towards the edge, or equator, of the lens the appearance and character of these cells undergo a change : they first gradually take on a columnar form, and then, becoming more and more elongated, present every transition to the nucleated lens-fibres of the superficial layers, into which they are directly continuous (see fig. 198).

The epithelium-cells are generally in close apposition, but are sometimes partially separated from one another by larger interstices which are bridged across by processes passing from cell to cell.[1]

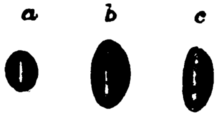

FIG. 200.—SIDE VIEW OF THE LENS AT DIFFERENT AGES.

a, at birth with the deepest convexity; *b*, in adult life with medium convexity; *c*, in old age with considerable flattening of the curvatures.

After death a small quantity of fluid (liquor Morgagni) frequently collects between the back of the lens and the capsule : it appears to be derived from the lens-fibres.

Changes in the lens with age.—In the *fœtus*, the lens is nearly spherical (fig. 200, *a*) : it has a slightly reddish colour, is not perfectly transparent, and is softer and more readily broken down than at a more advanced age.

In the *adult*, the anterior surface of the lens is distinctly less convex than the posterior (fig. 200, *b*), and the substance of the lens is firmer, distinctly yellowish (never colourless, according to Hess [2]), and transparent.

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[1] Hosch, Arch. f. Ophth. xx. 1874 ; Barabaschew, *ibid.* xxxviii. 1892.

[2] ‘Pathol. u. Therapie des Linsensystems,’ in Graefe-Saemisch, Handb. d. Augenheilk., 2nd edition, 1905.

In *old age*, it is more flattened on both surfaces (*c*); it assumes a deeper yellow or amber tinge, and is apt to lose its transparency and gradually to increase in toughness and specific gravity.

In most animals the lens is colourless, but it is said to be yellow in other Primates.

The lens becomes both larger in diameter and heavier throughout life (Priestley Smith [1]). Between the ages of twenty-five and sixty-five it increases in volume and weight by one-third. Its average weight, according to Priestley Smith, is 0·174 gr. between twenty and thirty, 0·192 gr. between thirty and forty, 0·204 gr. between forty and fifty, and 0·221 gr. between fifty and sixty.

Although the lens tends to become harder with age, the amount of water it contains is not diminished.[2]

Experiments which have been made with easily recognisable salts and with fluorescin tend to show that watery fluids penetrate into the lens at its equator, opposite the canal of Petit. They pass, however, very slowly into its substance, but it is more readily permeated by fluids which dissolve lipoid substances; these substances being contained in the lens-fibres to an appreciable amount.[3]

AQUEOUS HUMOUR.

The aqueous humour fills the space in the fore-part of the eyeball, between the capsule of the lens with its suspensory ligament and the cornea. The iris, resting in part upon the lens, divides the aqueous chamber partially into two, named respectively the anterior and posterior chambers. This subdivision is incomplete in the adult, but in the fœtus before the seventh month it is completed by the membrana pupillaris, which, by its union with the margin of the pupil, closes the aperture of communication between the two chambers.

The *anterior chamber* is limited in front by the cornea and behind by the iris, while opposite the pupil it is bounded by the front of the lens and its capsule.

The *posterior chamber* lies behind the iris. It is continuous through clefts in the anterior part of the suspensory ligament of the lens with the triangular space intervening between the margin of the lens, the anterior surface of the vitreous humour, and the ciliary body (canal of Petit), and it sends prolongations or pouches between the zonule and the pars ciliaris retinæ, as has already been described (p. 258). The aqueous humour is a clear watery fluid, of sp. gr. 1·0053, and amounts to less than one-third of a cubic centimetre.[4] It has a somewhat higher osmotic pressure than serum of blood.[5] A few leucocytes can sometimes be found in it. It is probably secreted mainly by the epithelium of the ciliary body and its glands. It finds exit mainly through the clefts of the ligamentum pectinatum iridis into the cavities at the angle of the anterior chamber, and thence into the canal of Schlemm and the venous system of that region; but in part through the anterior surface of the iris into lymph-spaces in the iris, and thence to the perichoroideal lymph-space.

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[1] Trans. of Ophth. Soc. vol. ii.

[2] W. J. Collins, Ophth. Review, 1889.

[3] Leber, Arch. f. Ophth. 1905. For observations on the chemical composition of the lens, see Bottazzi and Scalinci, Rend. d. r. acc. d. Lincei, 1908.

[4] In dogs of moderate size, E. Pflüger found the rate of secretion to be about 6–8 cubic millimetres a minute, and to be almost independent of the blood-pressure (Arch. f. Ophth. 1906). Golowin found the sp. gr. in the dog to be 1·008 to 1·009—equivalent to that of a solution of NaCl of rather more than 1 per cent. (Arch. f. Ophth. li. 1900).

[5] Kunst, Diss. Freiburg, 1895; Hamburger, Osmotischer Druck u. Tonenlehre, 1904.

THE EAR.

The organ of hearing comprises three parts: the external ear (fig. 201, 1, 2), the middle ear (3), and the labyrinth or internal ear (6). The first two of these are to be considered as accessories to the third, which is the portion of the organ to which the fibres of the eighth or acoustic nerve are distributed.

THE EXTERNAL EAR.

In the external ear are included the *pinna*—the part of the outer ear which projects from the side of the head—and the *meatus* or passage which leads thence to the tympanum, and which is closed at its inner extremity by a membrane interposed between it and the middle ear.

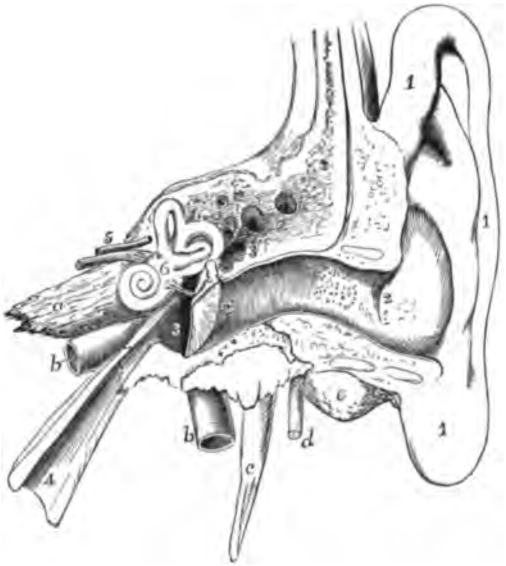

FIG. 201.—DIAGRAMMATIC VIEW FROM BEFORE OF THE PARTS COMPOSING THE ORGAN OF HEARING OF THE LEFT SIDE. (After Arnold.)

The temporal bone of the left side, with the accompanying soft parts, has been detached from the head, and a section has been carried obliquely through it so as to remove the front of the meatus externus, half the tympanic membrane, and the upper and anterior wall of the tympanum and Eustachian tube. The meatus internus has also been opened, and the bony labyrinth exposed by the removal of the surrounding parts of the petrous bone.

1, the pinna and lobule; 2 to 2′, meatus externus; 2′, membrana tympani; 3, cavity of the tympanum; above 3, the chain of small bones; 3′, opening into the mastoid cells; 4, Eustachian tube; 5, meatus internus, containing the facial (uppermost) and acoustic nerves; 6, placed on the vestibule of the labyrinth above the fenestra vestibuli; *a*, apex of the petrous bone; *b*, internal carotid artery; *c*, styloid process; *d*, facial nerve issuing from the stylo-mastoid foramen; *e*, mastoid process; *f*, squamous part of the bone.

THE PINNA.

The general form of the pinna or auricle, as seen from the outside, is concave, to fit it for collecting and concentrating the undulations of sound, but it is thrown into various elevations and hollows, to which distinct names have been given (fig. 202). The largest and deepest concavity is called the *concha*; it surrounds the entrance to the meatus, and is interrupted at its upper and anterior part by a ridge, which is the beginning of the helix. In front of the concha, and projecting outwards and backwards over the meatus, is a conical prominence, the *tragus*, covered usually with hairs. Its upper part sometimes forms a rounded prominence (*tuberculum supratragicum*, His). Behind the tragus, and separated from it by a deep notch (*incisura intertragica*), is another smaller elevation, the *antitragus*, which bounds the concha inferiorly. Below the antitragus, and forming the lower end of the auricle, is the *lobule*, which is devoid of the firmness and elasticity that characterise the rest of the pinna. The thinner and larger portion of the pinna is bounded by a prominent and incurved margin, the *helix*, which, springing above and behind the tragus, from the hollow of the concha, surrounds the upper and posterior margin of the auricle, and gradually loses itself in the back part of the lobule. Within the helix is another curved ridge, the *anthelix*, which, beginning below at the antitragus, ascends behind the hollow of the concha, and divides above into two ridges. The lower of these two ridges bounds the concha superiorly. Between the helix and the anthelix is a narrow curved groove, the *fossa scaphoidea*; and in the fork of the anthelix is a somewhat triangular depression, the *fossa triangularis*.

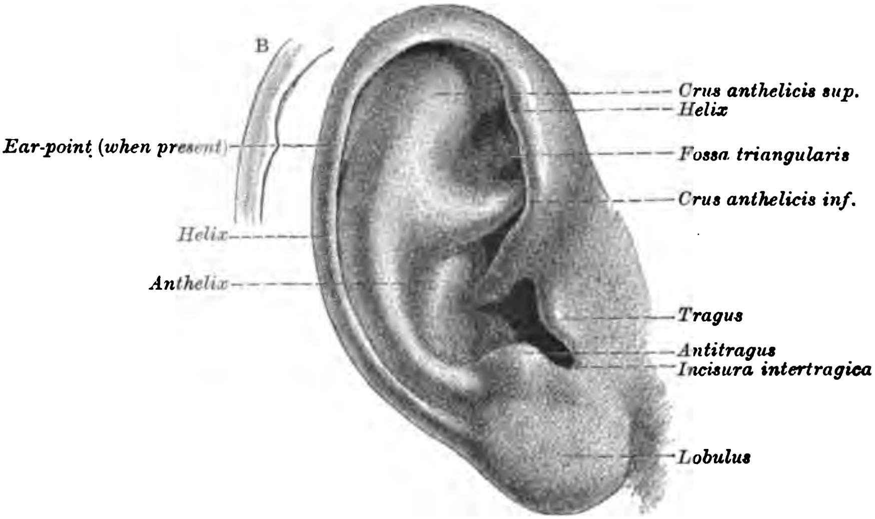

FIG. 202.—OUTER SURFACE OF THE RIGHT AURICLE. (After Arnold.)
B, sketch showing the 'ear-point' of Darwin, sometimes present.

Ear-point: tubercle of Darwin.—Slight projections are occasionally observed in the human subject at the margin of the helix. One of these to which Darwin's attention was drawn by Mr. Woolner, the sculptor, is of interest as representing the much more distinct pointed extremity met with in the expanded ears of quadrupeds.[1] The point in question is represented in the sketch given in fig. 202, B. It is constant in the embryo of about the sixth month, where it presents a relative extent of development which is permanent in certain monkeys (Schwalbe). In the adult it occurred in about 30 per cent. of cases examined.[2]

Considerable variation is met with in the size and shape of the pinna,[3] in its amount of projection from the side of the head, in the extent of folding which it exhibits, and in the size of the lobule, and this is not only in individuals of different races, but even in those belonging to the same family. Attempts have been made to use these variations as a basis of classification in criminal anthropology, but with results of very doubtful value. The lobule is usually regarded as a human characteristic, but it is sometimes found fairly well developed in anthropoids, and is often very little developed in man.

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[1] Darwin, The Descent of Man, 1871.

[2] Blau, Corresp.-bl. d. deutsch. Ges. f. Anthrop. xxxvii. 1907.

[3] The relation of the transverse to the longitudinal measurement of the pinna is known as the ear-index $\left(\frac{T \times 100}{L}\right)$, and is employed in anthropometry.

Structure.—The pinna consists mainly of yellow fibro-cartilage and integument, with a certain amount of adipose tissue. It has several ligaments and small muscles of minor importance.

The *skin* covering it is thin, closely adherent to the cartilage, especially on the concave aspect, and is covered with hairs which are provided with large sebaceous follicles. It also contains sweat-glands on the convex aspect, but few or none on the concave side. In the external auditory meatus these reappear in a modified form as the ceruminous glands. The hairs of the pinna are most numerous and longest on the tragus and antitragus. The hairs on the margin and convex aspect of the ear are arranged with a general tendency to point towards the tubercle of Darwin, where the converging series may even form a distinct tuft, thus furnishing an additional argument in favour of the view regarding the meaning of that prominence which was taken by Darwin.

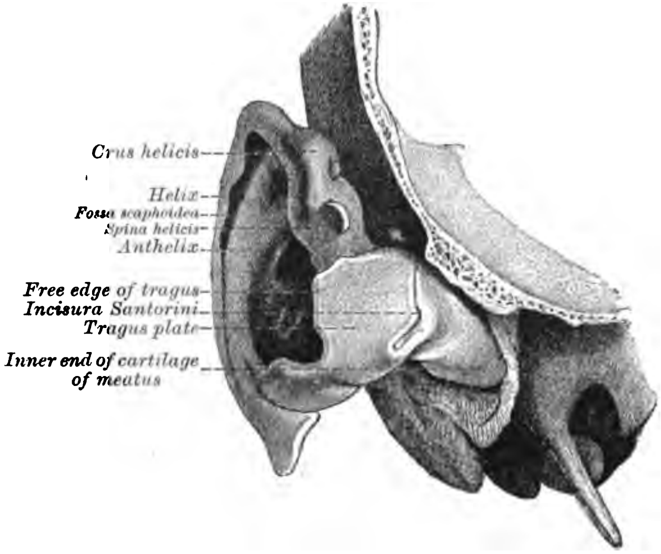


FIG. 203.—RIGHT EAR-CARTILAGE, ANTERIOR ASPECT. (Arnold.)

The *cartilage* (figs. 203 to 205) forms a plate 1 mm. to 3 mm. thick, with all the inequalities already described as apparent on the outer surface of the pinna, and on its cranial surface having prominences the reverse of the concha and the fossa of the helix, while between these is a depression in the situation of the anthelix. The cartilage is not confined to the pinna, but enters likewise into the construction of the outer part of the external auditory canal. The auricular portion closely resembles in its form that of the entire pinna, except that it has no lobule and possesses several fissures that do not involve its cutaneous covering. The *terminal fissure* (fig. 204) passes downwards between the tragus and the helix to open into the upper part of the entrance to the auditory meatus. This is not a true fissure of the cartilage, but is due to the lower and anterior part of the cartilaginous plate being turned upwards towards the helix so as to form the anterior wall of the concha and of the adjacent portion of the auditory meatus. Another fissure extends upwards between the tail of the helix and the stem of the anthelix. At the fore-part of the pinna, opposite the first bend of the helix, is a small conical projection of the cartilage, called the *spine of the helix*, to which the anterior ligament is attached. Behind this process is a short vertical slit in the helix; and on the surface of the tragus is a similar but somewhat longer fissure.

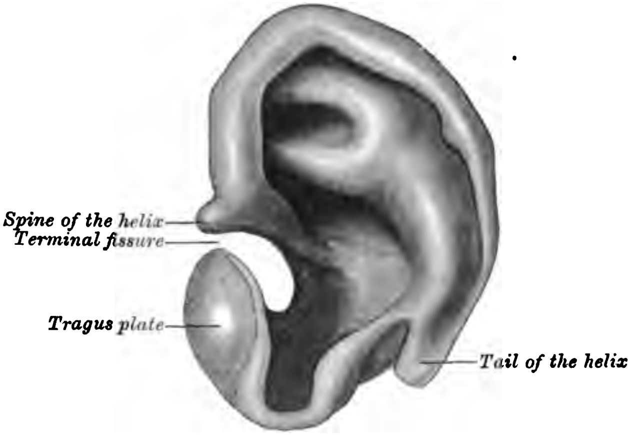

Spine of the helix
Terminal fissure
Tragus plate
Tail of the helix

Fig. 204.—Ear-cartilage, lateral aspect. (J. Symington.)

The narrow bridge of cartilage between the floor of the entrance to the meatus and the *incisura intertragica*, and which unites the greater part of the cartilaginous pinna with that of the tragus and the auditory plate, is termed the *isthmus*. The outer border of the cartilage of the tragus forms the prominence of the tragus, while its upper border turns backwards and is united with the helix by fibrous tissue. Internally the cartilage of the tragus is continuous with the slightly curved tragus plate which forms the anterior wall and the floor of the cartilaginous portion of the meatus, and is fixed by fibrous tissue to the rough auditory process of the tympanic plate of the temporal bone. This incomplete

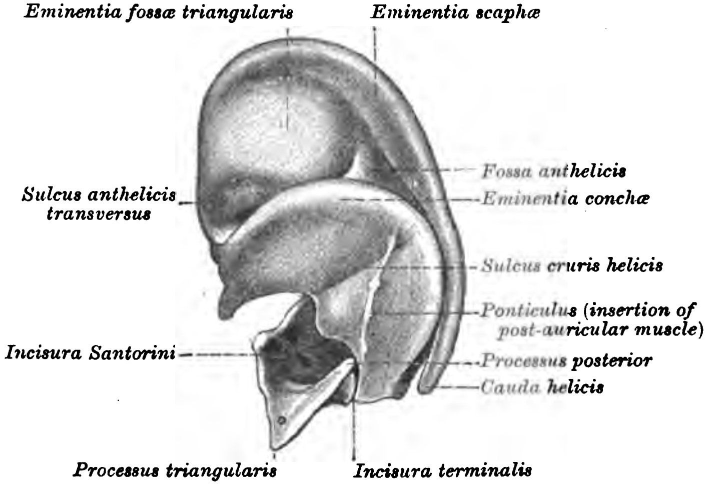

Eminentia fossæ triangularis
Eminentia scaphæ
Sulcus anthelicis transversus
Fossa anthelicis
Eminentia conchæ
Sulcus cruris helicis
Ponticulus (insertion of post-auricular muscle)
Incisura Santorini
Processus posterior
Cauda helicis
Processus triangularis
Incisura terminalis

Fig. 205.—Ear-cartilage, mesial aspect. (Schwalbe.)

cartilaginous tube has two fissures running transversely to the long axis of the meatus, which are called the fissures of Santorini. The substance of the cartilage is very pliable, and is covered by a firm fibrous perichondrium. Near its attachment to the bone it becomes hyaline.

Ligaments.—Of the *ligaments of the pinna*, the most important are two which assist in attaching it to the side of the head. The *anterior* ligament, broad and strong, extends from the spine of the helix to the root of the zygoma. The *posterior* ligament consists of loose fibrous tissue uniting the back of the auricle (opposite the concha) to the outer surface of the mastoid process of the temporal bone. A few fibres attach the tragus also to the root of the zygoma. Ligamentous fibres are likewise placed across the fissures and intervals left in the cartilage (*intrinsic ligaments*).

Muscles.—Of the muscles of the pinna, those which are attached by one end to the side of the head, and move the pinna as a whole, are described in the 'Myology'; there remain to be noticed several smaller muscles, composed of thin layers of pale-looking fibres, which extend from one part of the pinna to another, and may be termed the intrinsic muscles of the auricle. Six such small muscles are distinguished, four being on the outer and two on the inner or deep surface of the pinna.

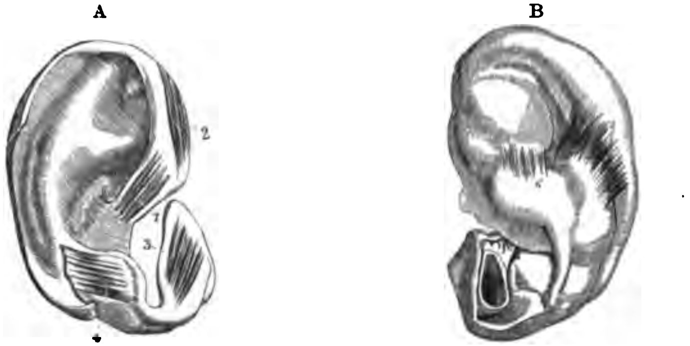


Fig. 206, A and B.—Outer and inner surfaces of the right pinna, exposed to show the small muscles. (From Arnold.)

1, musculus helicis minor; 2, m. helicis major; 3, m. tragicus; 4, m. antitragicus; 5, m. transversus auriculæ; 6, m. obliquus auriculæ.

The *smaller muscle of the helix* (fig. 206, 1) is a small bundle of oblique fibres, lying over, and firmly attached to, that portion of the helix which springs from the bottom of the concha. As with the other intrinsic muscles, its fibres are, in part, attached to the skin.

The *greater muscle of the helix* (2) lies vertically along the anterior margin of the pinna. By its lower end it is attached to the spine of the helix; above, its fibres terminate opposite the point at which the ridge of the helix turns backwards. The anterior auricular muscle is sometimes continued partly into this muscle.

The *muscle of the tragus* (3) is a flat bundle of short fibres covering the outer surface of the tragus: its direction is nearly vertical. Occasionally a slender bundle of muscular fibres is seen prolonging this muscle across the cleft in the cartilage between the tragus and fore-part of the helix to be attached to the spine of the helix (*m. pyramidalis*, Jung). Another muscle (*dilatator conchæ*, Theile) of less constant occurrence lies upon the anterior face of the tragus, bridging over the greater fissure of Santorini, which is there present.

The *muscle of the antitragus* (4) is placed obliquely over the antitragus and behind the lower part of the anthelix. It is fixed at one end to the antitragus, from which point its fibres ascend somewhat to be inserted into the caudate process of the helix, above and behind the lobule.

The *transverse muscle* (5) lies on the inner or cranial surface of the pinna, and consists of radiating fibres which extend from the back of the concha to the prominence which corresponds with the groove of the helix.

The *oblique muscle* (Tod) (6) consists of a few fibres stretching from the back of the concha to the convexity directly above it, across the back of the inferior branch of the anthelix, and near the fibres of the transverse muscle.

The muscles of the tragus and antitragus tend to contract the entrance to the meatus when stimulated by electricity (Duchenne), the muscles of the helix having a contrary tendency. They are none of them under the influence of the will, but it is possible they may act slightly in a reflex manner. All the ear-muscles are supplied by the facial nerve.

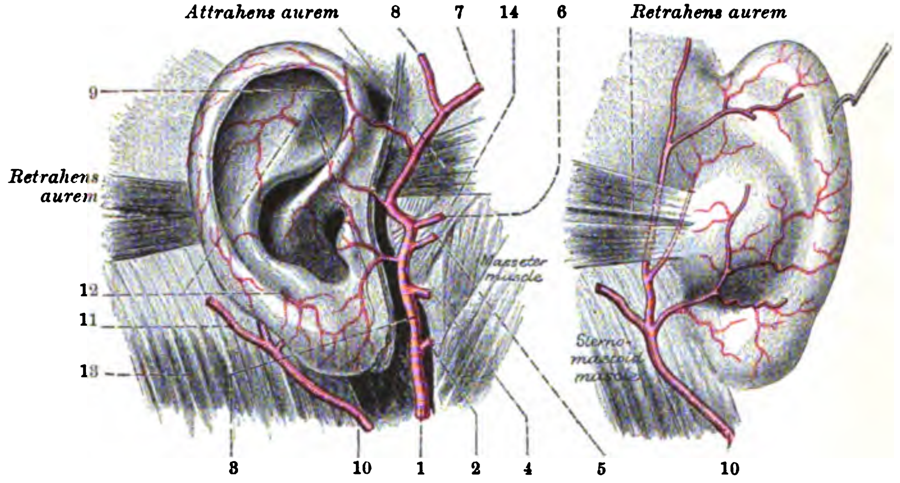


FIG. 207.—ARTERIES SUPPLYING THE AURICLE. (Testut.)

1, external carotid; 2, internal maxillary; 3, superficial temporal; 4, transverse facial; 5, middle temporal; 6, orbital branch of temporal; 7, anterior terminal branch; 8, posterior terminal branch; 9, anterior auricular branches; 10, posterior auricular artery; 11, its mastoid branch; 12, perforating branches; 13, sterno-mastoid muscle; 14, capsule of temporo-maxillary joint.

Vessels of the pinna (fig. 207).—The auricular branch of the *posterior auricular artery*, a branch from the external carotid, is distributed chiefly on the mesial surface, but some of its branches turn over the folded margin to reach the lateral surface of the helix: others pierce the cartilage and ramify on the lateral surface of the anthelix, concha, and lobule. Besides this artery, the auricle receives the *anterior auricular* branches from the superficial temporal. These chiefly supply the anterior part of the lobule, the tragus, and the anterior part of the helix.

The *veins* for the most part accompany the arteries. They join the posterior auricular and temporal veins, but some enter the mastoid emissary vein of the lateral sinus. The *lymphatics* of the pinna pass partly forwards from the concha to join a gland in front of the tragus; partly downwards and backwards from the upper and posterior part of the pinna towards the mastoid glands; and partly downwards from the lobule towards the parotid lymphatic glands.

Nerves.—The *great auricular nerve,* from the cervical plexus, supplies the integument of the greater part of the mesial surface of the auricle, and sends small branches to the lateral surface behind a line prolonged downwards from near the highest part of the helix through the fissura intertragica, with the exception of a small area in the concha supplied by the vagus. The auricular branch of the *posterior auricular nerve,* derived from the facial, after communicating with the *auricular branch of the pneumogastric,* ramifies on the back of the ear, supplying the small muscles. The *auriculo-temporal* branch of the third division of the fifth nerve gives filaments to the tragus and the crus and ascending limb of the helix. A branch of the *small occipital* supplies the upper part of the mesial surface. Filaments from the temporal branches of the facial supply the external muscles.

THE EXTERNAL AUDITORY CANAL.

The external auditory canal, *meatus acusticus externus,* extends from the bottom of the concha to the membrane of the tympanum and serves to convey the vibrations of sound to the middle chamber of the ear. Its outer boundary may be regarded as lying in a sagittal plane opposite where the posterior wall of the meatus turns backwards into the floor of the concha, but the anterior wall of the meatus is sometimes described as extending outwards beyond this plane—viz. to the outer border of the tragus and the inferior wall to the *incisura intertragica.* Even although the outer boundary be described as being in a sagittal plane, the walls are unequal in length owing to the obliquity of the line of attachment of the membrana tympani, which is directed from above, downwards and inwards, and from behind, forwards and inwards, so that the lower and anterior part of the meatus reaches 5 mm. to 6 mm. nearer the median plane than the upper and posterior portion. The posterior part is

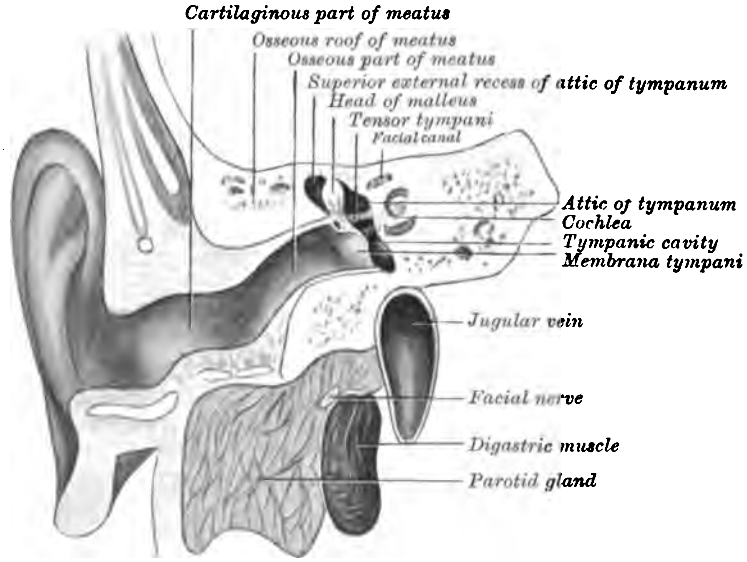

Cartilaginous part of meatus
Osseous roof of meatus
Osseous part of meatus
Superior external recess of attic of tympanum
Head of malleus
Tensor tympani
Facial canal
Attic of tympanum
Cochlea
Tympanic cavity
Membrana tympani
Jugular vein
Facial nerve
Digastric muscle
Parotid gland

FIG. 208.—CORONAL SECTION OF EXTERNAL AUDITORY MEATUS, TYMPANIC CAVITY, AND COCHLEA, VIEWED FROM THE FRONT. Natural size. (J. Symington.)

The section is anterior to the internal auditory meatus and the facial canal is opened where it bends backwards.

the shortest, and measures on an average 24 mm. The anterior, measured to the outer border of the tragus, is about 35 mm. The main direction of the external auditory meatus is horizontally inwards, but it is not quite straight, for the outer portion is usually inclined upwards and backwards, while near the membrana tympani the meatus turns slightly forwards and downwards. The calibre of the passage is smallest in the osseous part of the canal a few millimetres from the membrana tympani; it is also somewhat contracted near the end of the cartilaginous portion. Its form and dimensions have been studied by v. Bezold, chiefly by means of casts of the cavity (fig. 211): the results of the transverse measurements at certain points are given in the accompanying diagram (fig. 212). At the inner extremity the tube is terminated by the obliquely placed membrana tympani.

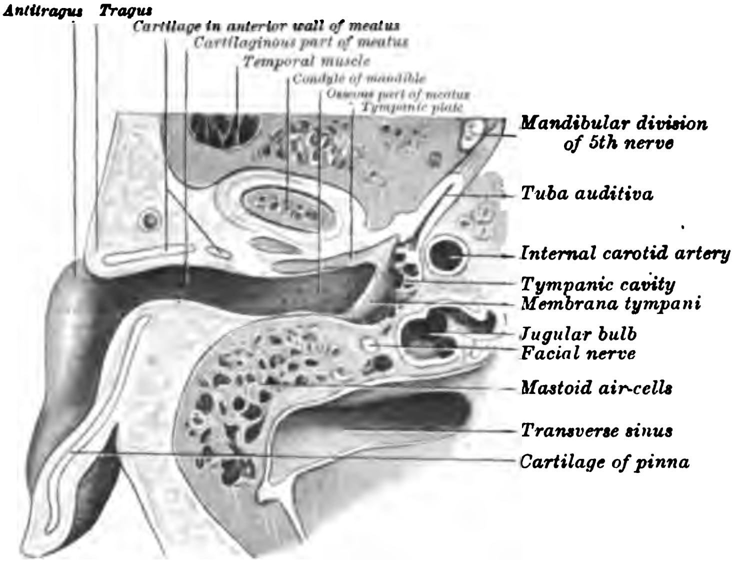

Antitragus
Tragus
Cartilage in anterior wall of meatus
Cartilaginous part of meatus
Temporal muscle
Condyle of mandible
Osseous part of meatus
Tympanic plate
Mandibular division of 5th nerve
Tuba auditiva
Internal carotid artery
Tympanic cavity
Membrana tympani
Jugular bulb
Facial nerve
Mastoid air-cells
Transverse sinus
Cartilage of pinna

FIG. 209.—HORIZONTAL SECTION OF EXTERNAL AUDITORY MEATUS OF LEFT SIDE, VIEWED FROM ABOVE. Natural size. (J. Symington.)

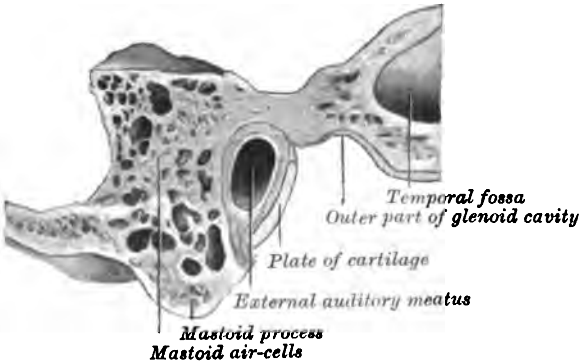

Temporal fossa
Outer part of glenoid cavity
Plate of cartilage
External auditory meatus
Mastoid process
Mastoid air-cells

FIG. 210.—SAGITTAL SECTION OF THE CARTILAGINOUS PORTION OF THE RIGHT EXTERNAL AUDITORY MEATUS, VIEWED FROM THE LATERAL ASPECT. Natural size. (J. Symington.)

Structure.—The wall of the meatus is composed partly of cartilage and partly of bone, and is lined by a prolongation of the skin.

The *cartilaginous* part occupies somewhat less than half the length of the passage. It is formed, as already mentioned, by an inflection of the deep part of the cartilage of the pinna, which at the entrance of the meatus forms a ring which is complete except above, but internal to this a slightly curved plate, found only in the anterior wall and floor of the meatus, the tube being completed above and behind by fibrous tissue.

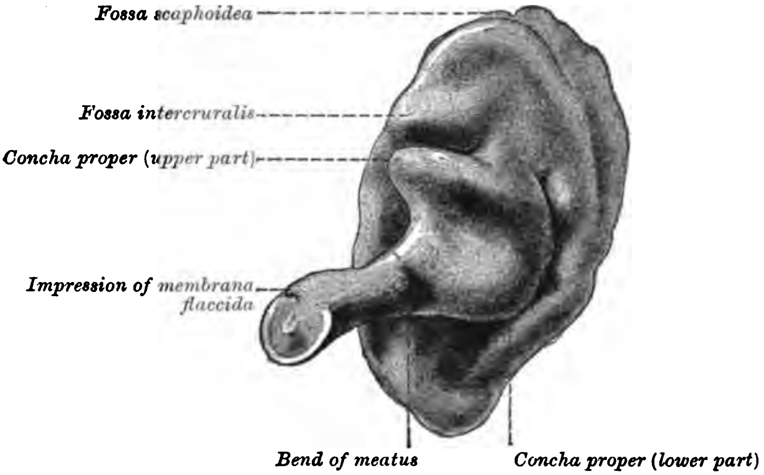

Fossa scaphoidea
Fossa intercruralis
Concha proper (*upper part*)
Impression of membrana flaccida
Bend of meatus
Concha proper (*lower part*)

FIG. 211.—CAST OF THE EXTERNAL AUDITORY MEATUS. (Bezold.)

The *osseous portion* is a little longer and on the whole rather narrower than the cartilaginous part. It is formed in front, below, and behind by the tympanic plate of the temporal bone, and is completed above by the squamous part. At the inner end of the meatus the tympanic plate has a narrow and shallow groove (*sulcus tympanicus*) to which the tympanic membrane is attached. There is no corresponding groove above where the ring is completed by the squamous part, but in this situation there is a small notch (*notch of Rivinus*).

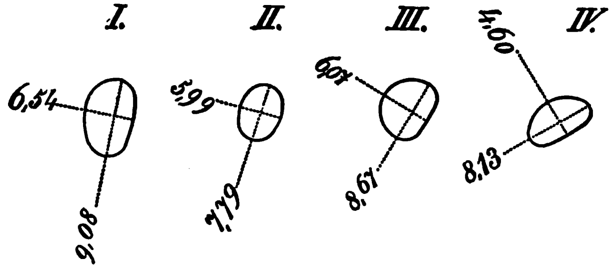


FIG. 212.—DIAGRAM SHOWING THE FORM AND MEASUREMENTS OF SECTIONS ACROSS THE EXTERNAL AUDITORY MEATUS. Natural size. (Bezold.)

I., at commencement of cartilaginous portion; *II.*, near end of cartilaginous portion; *III.*, near beginning of osseous portion; *IV.*, near end of osseous portion.

The *skin* of the meatus is continuous with that covering the pinna, but is very thin in the osseous part, especially at the bottom of the passage. Here it adheres very closely to the periosteum, and has no hairs or glands, but is provided with vascular papillæ (ridges, according to Kaufmann). At the end of the tube the epithelial portion of the skin is prolonged over the surface of the membrana tympani, forming the outer layer of that structure. Towards the outer part of the roof of the osseous portion and throughout the cartilaginous portion the skin possesses fine hairs and sebaceous glands; and in the thick subdermic tissue are small oval convoluted tubular glands of a brownish-yellow colour, agreeing in form and structure with the sweat-glands, but larger in part or entirely, and in sufficient number at some parts, especially where cartilage is deficient, to form an almost complete layer in the subcutaneous tissue. The cerumen or ear-wax is secreted by these glands (*glandulæ ceruminosæ*); their fine ducts may be seen to perforate the skin of the meatus close to or into the mouths of the hair-follicles. According to Schwalbe, the fatty part of the ear-wax is formed by the sebaceous glands. This may be partly the case, but the secretion of the ceruminous glands is certainly also of a fatty nature (fig. 218).

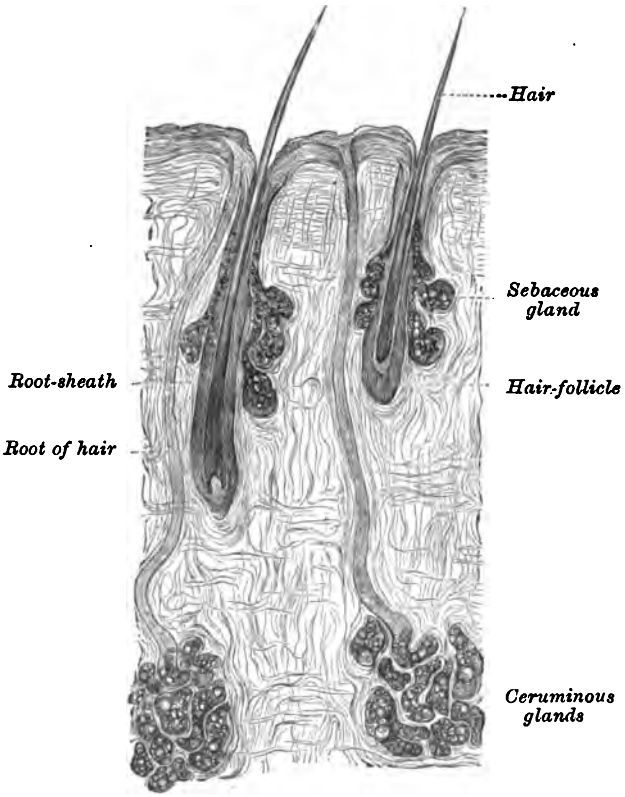


FIG. 218.—SECTION OF SKIN OF AUDITORY MEATUS, INCLUDING TWO CERUMINOUS GLANDS. (Grüber.)

Vessels and nerves.—The external auditory meatus is supplied with arteries from the *posterior auricular*, *internal maxillary*, and *temporal* arteries. The principal branches of the arteries course along the upper and back wall of the canal. The veins and lymphatics take the same course on leaving the meatus as do the corresponding vessels of the pinna. The nerves are derived from the auriculo-temporal branch of the trifacial and the auricular branch of the vagus, the former supplying the anterior and the latter the posterior part of the meatus.

Relations.—Behind the meatus is the mastoid portion of the temporal bone, usually more or less hollowed out into air-cells. Still farther back lie the transverse sinus and the cerebellum. The most important anterior relation is the condyle of the lower jaw, and in front of the cartilaginous portion there is a process of the parotid gland, which also lies in contact with the greater part of the floor. The thick bony roof of the meatus separates the osseous part of the meatus from the temporal lobe of the cerebrum. The upper part of the tympanic cavity (*recessus epitympanicus*) extends outwards so as to be situated above the inner end of the meatus.

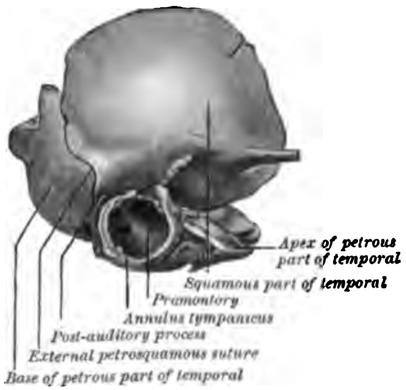

Apex of petrous part of temporal
Squamous part of temporal
Promontory
Annulus tympanicus
Post-auditory process
External petrosquamous suture
Base of petrous part of temporal

FIG. 214.—LATERAL ASPECT OF TEMPORAL BONE OF NEWLY BORN INFANT. Natural size. (J. Symington.)

State in the infant.—At birth there is no distinct osseous meatus. The tympanic element is in the form of an incomplete ring to which the membrana tympani is attached. On the outer side of the ring is a fibrous plate occupying the same position in the wall of the meatus as the future tympanic plate. The cartilaginous portion of the meatus does not differ essentially from that of the adult, and the entire meatus is relatively fully as long as in the adult. In the newly born child the meatus is nearly closed by the approximation of its roof and floor, except near the outer end where it is occupied by epithelial cells and ear-wax, but it soon opens up and ossification begins to extend from the annulus tympanicus into the fibrous plate. This growth does not occur uniformly from the tympanic ring, but mainly from two tubercles, situated one near the upper end of its anterior limb and another at its lower part, so that the outer edge of the tympanic bone at this stage exhibits a notch which by the subsequent union of the two tubercles is converted into a foramen. This aperture occasionally persists until adult life, and in cases where it is closed the osseous wall remains thin in this situation. While these changes in the tympanic element are forming an osseous wall for the meatus in front, below and behind, the squamous part of the temporal situated above the membrana tympani grows outwards, and comes to lie nearly at a right-angle with the vertical plate of the squamosa so as to form an osseous roof. The formation of a distinct osseous meatus is usually completed during the second year. At birth the floor of the meatus is about 20 mm. long and the roof 15 mm. The meatus is about the same length at the end of the first year, for the opening up of the meatus after birth appears to be associated with some shortening of the tube, as in an infant two months old it measured 17 mm. on the floor and 13 mm. along the roof. After the first year the meatus slowly increases in length, being about 2 mm. longer at the end of the second year and 4 mm. longer in the fifth year.

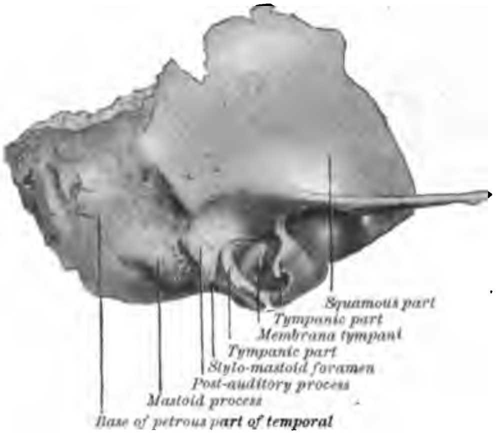

Squamous part
Tympanic part
Membrana tympani
Tympanic part
Stylo-mastoid foramen
Post-auditory process
Mastoid process
Base of petrous part of temporal

FIG. 215.—LATERAL ASPECT OF TEMPORAL BONE OF INFANT TWELVE MONTHS OLD. Natural size. (J. Symington.)

THE MIDDLE EAR.

The middle ear consists of an air-passage, derived from the inner or pharyngeal portion of the first visceral cleft, which passes from the lateral wall of the pharynx backwards, outwards, and upwards into the temporal bone. This air-passage communicates with the exterior through the nasopharynx, choana, nasal cavity, and naris. It is divided into three main portions—an anterior *tuba auditiva* (Eustachian tube); a middle, *tympanum* or *cavum tympani* (drum of the ear), situated between the external and internal ear and traversed by a chain of small bones; and a posterior, *antrum tympani* (mastoid antrum), which lies behind the tympanum and ends blindly in the fœtus, but subsequently communicates by numerous apertures with a complicated system of air-spaces termed the *cellulæ mastoideæ*. The total length of the passage, measured from the pharyngeal end of the tuba auditiva to the posterior wall of the antrum tympani, is nearly 6 cm.

The *tuba auditiva* (Eustachian tube, salpinx) is a canal about 36 mm. long, passing from the nasopharynx backwards, outwards, and upwards to the tympanum at an angle of 45 degrees from the sagittal plane, and about 30 degrees from the horizontal plane. The upward inclination is slightly greater in the anterior or cartilaginous than in the posterior or osseous part of the tube.

The *cartilaginous* portion, about 26 mm. long, is formed by an irregularly triangular plate of cartilage, which is situated mainly in the mesial wall of the tube, and gradually diminishes in vertical extent from its pharyngeal end towards the tympanum. In sections made at right-angles to the tube the cartilaginous plate is seen to terminate below in a thick rounded border, but above to have a hook-like process passing outwards over the tube and descending a short distance into the outer wall.

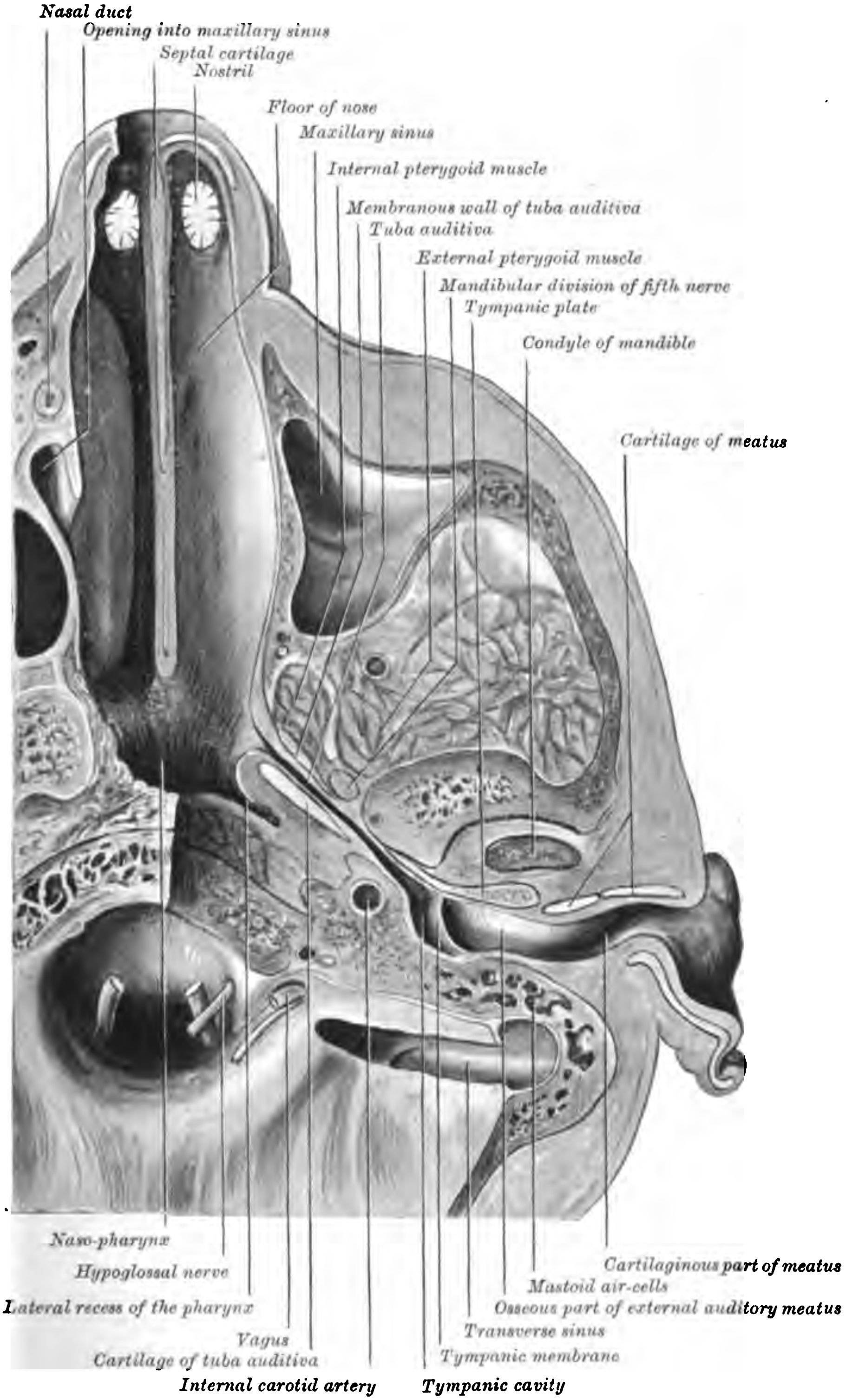
When the tube is opened by a longitudinal section dividing its outer and inner wall, the tympanic end of the cartilaginous plate is found to be united by fibrous tissue to the temporal bone, and the pharyngeal end to project, covered by mucous membrane, towards the nasopharynx and form a prominence between the orifice of the tube and the lateral recess of the pharynx. The cartilage is sometimes broken up by fissures, or there may be accessory pieces of cartilage in various situations in the wall of the tube. In the greater part of the outer wall and in the floor, where the cartilage is absent, the wall is completed by dense but pliable fibrous tissue (*fascia salpingo-pharyngea*), and by a muscular band connected with the tensor palati, and termed by Rüdinger the *dilatator tubæ*.

The cartilaginous part of the tube is lined by mucous membrane provided with ciliated columnar epithelium, under which are collections of lymphoid tissue and numerous mucous glands. The lymphoid tissue is most abundant near the pharyngeal orifice and in young subjects.

Except at the pharyngeal orifice, the cartilaginous part of the tube is generally closed by the apposition of its lateral walls, so that on transverse section its lumen appears as a vertical slit which is 1 mm. or 2 mm. in length at its junction with the osseous portion (*isthmus tubæ*), but gradually increases towards the

Fig. 216.—Drawing to illustrate air-passages connected with the ear. Natural size. (J. Symington.)

The section on the right half is not all in the same plane. Thus, that exposing the external auditory meatus and tympanum is horizontal; in front of these cavities it inclines downwards and forwards, so as to open the Eustachian tube, and then again passes horizontally, above the floor of the nose.


Nasal duct
Opening into maxillary sinus
Septal cartilage
Nostril
Floor of nose
Maxillary sinus
Internal pterygoid muscle
Membranous wall of tuba auditiva
Tuba auditiva
External pterygoid muscle
Mandibular division of fifth nerve
Tympanic plate
Condyle of mandible
Cartilage of meatus
Naso-pharynx
Hypoglossal nerve
Lateral recess of the pharynx
Vagus
Cartilage of tuba auditiva
Internal carotid artery
Cartilaginous part of meatus
Mastoid air-cells
Osseous part of external auditory meatus
Transverse sinus
Tympanic membrane
Tympanic cavity

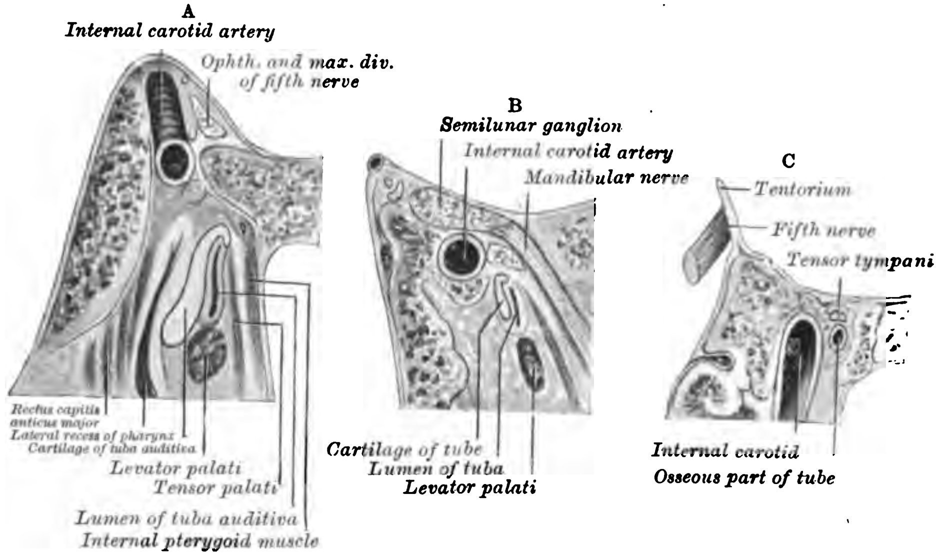

A
Internal carotid artery
Ophth. and max. div. of fifth nerve
Rectus capitis anticus major
Lateral recess of pharynx
Cartilage of tuba auditiva
Levator palati
Tensor palati
Lumen of tuba auditiva
Internal pterygoid muscle
B
Semilunar ganglion
Internal carotid artery
Mandibular nerve
Cartilage of tube
Lumen of tuba
Levator palati
C
Tentorium
Fifth nerve
Tensor tympani
Internal carotid
Osseous part of tube

FIG. 217.—THREE SECTIONS THROUGH THE RIGHT TUBA AUDITIVA, MADE AT RIGHT-ANGLES TO ITS LONG AXIS, VIEWED FROM BEHIND. Natural size. (J. Symington.)

A, just behind pharyngeal orifice. B, 10 mm. behind A. C, 15 mm. behind B.

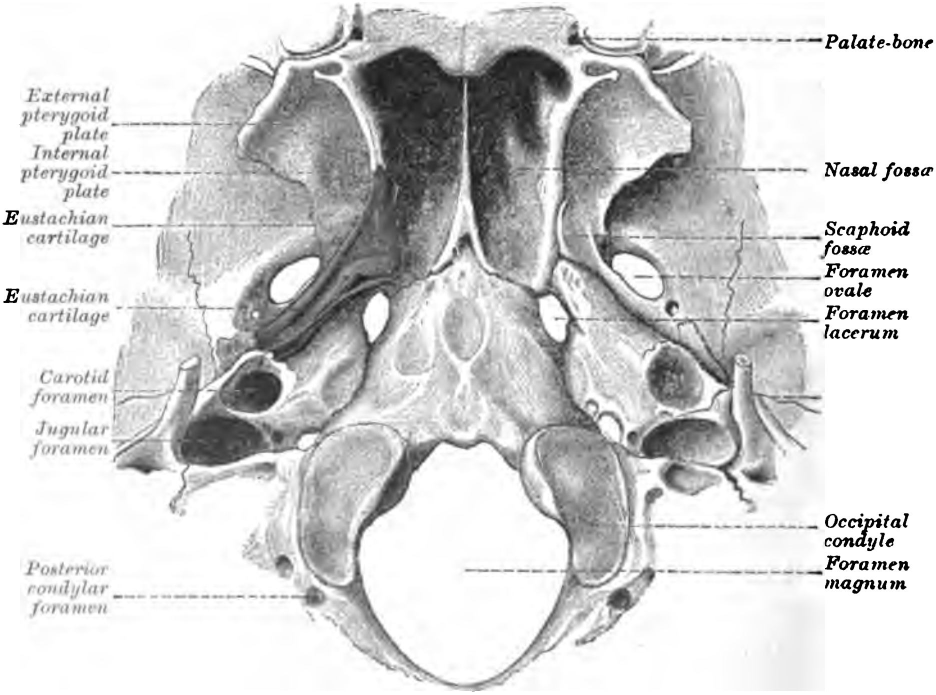

External pterygoid plate
Internal pterygoid plate
Eustachian cartilage
Eustachian cartilage
Carotid foramen
Jugular foramen
Posterior condylar foramen
Palate-bone
Nasal fossæ
Scaphoid fossæ
Foramen ovale
Foramen lacerum
Occipital condyle
Foramen magnum

FIG. 218.—BASE OF THE SKULL, SHOWING THE POSITION OF THE EUSTACHIAN CARTILAGE. (Modified from Testut.)

anterior end to 8 mm. or 10 mm. The pharyngeal orifice has the form of a compressed oval and is placed obliquely at the side of the nasopharynx behind the inferior turbinate process of the nose and above the level of the hard palate. Its prominent posterior boundary is continued below into the salpingo-pharyngeal fold. Below, the orifice is limited by a thickening, increased when the levator palati contracts, continued from a fold (*salpingo-palatine*), which also assists in forming the anterior boundary of the orifice.

The tube is fixed to the base of the skull by dense fibrous tissue, and the levator palati is just below it. The tensor palati is partly attached to the hooked part of its cartilage and to the fibrous tissue completing the lateral wall. The third division of the fifth nerve and the middle meningeal artery are lateral to it, while the anterior part of the mesial wall is in front of the lateral recess of the pharynx.

The *osseous* division of the tube, about 10 mm. long, is placed at the angle of junction of the petrous portion of the temporal bone with the squamous portion.

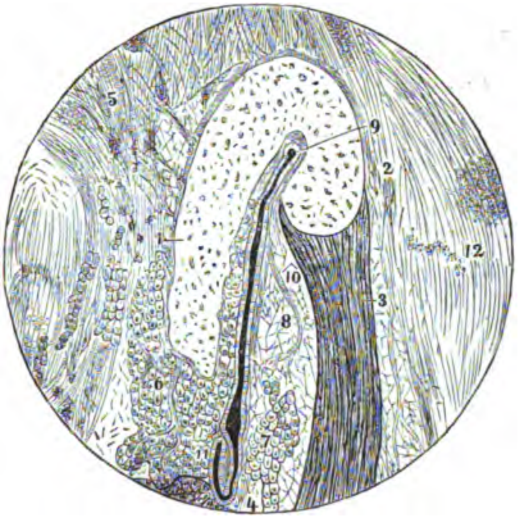


FIG. 219.—SECTION ACROSS THE CARTILAGINOUS PART OF THE EUSTACHIAN TUBE. (Rüdinger.)

1, 2, bent cartilaginous plate; 3, musc. dilatator tubæ; to the left of 4, part of the attachment of the levator palati muscle; 5, tissue uniting the tube to the base of the skull; 6 and 7, mucous glands; 8, 10, fat; 9 to 11, lumen of the tube; 12, connective tissue on the lateral aspect of the tube.

It is funnel-shaped, diminishing somewhat rapidly in size from behind forwards to the junction with the cartilaginous part; here the tube is narrowest (*isthmus tubæ*). The carotid canal lies mesially to the osseous portion of the tube, and is occasionally found to communicate with it owing to deficiencies in the bony septum between them. Above it is the canal containing the tensor tympani muscle. Several small air-cells communicate with this part of the tube.

The mucous membrane lining the osseous portion of the tube is thin and closely attached to the bone except along the floor of the canal, where it is separated from the periosteum by a venous plexus. It is lined by ciliated epithelium, and has no glands opening into it.

Vessels and nerves.—The *arteries* of the tube are derived on the one hand from the pharyngeal branch of the external carotid, and on the other from the middle meningeal and Vidian branches of the internal maxillary. The *nerves* arise from the tympanic plexus and pharyngeal twigs of the Vidian nerve.

Muscles.—Besides the middle part of the tensor palati muscle, which takes origin along the whole length of the lateral plate of the hooked cartilage of the tube (fig. 219), the levator palati also has an attachment to the commencement of the lateral plate, and from the adjacent membranous part of the floor of the tube, parallel to which its fibres course towards their insertion into the soft palate. When the muscle contracts the membranous floor of the tube is tightened, and is also raised near the ostium pharyngeum by the thickening of the muscular fibres which run just below it, and this helps to open the lower orifice during swallowing.

Lastly, some muscular bundles, forming the salpingo-pharyngeus of Santorini, arise from the lower and fore part of the mesial plate of cartilage, and, passing down immediately beneath the mucous membrane, join the palato-pharyngeus. This muscle tends to drag the mesial plate backwards and downwards, and thus assists in opening the tube during deglutition.

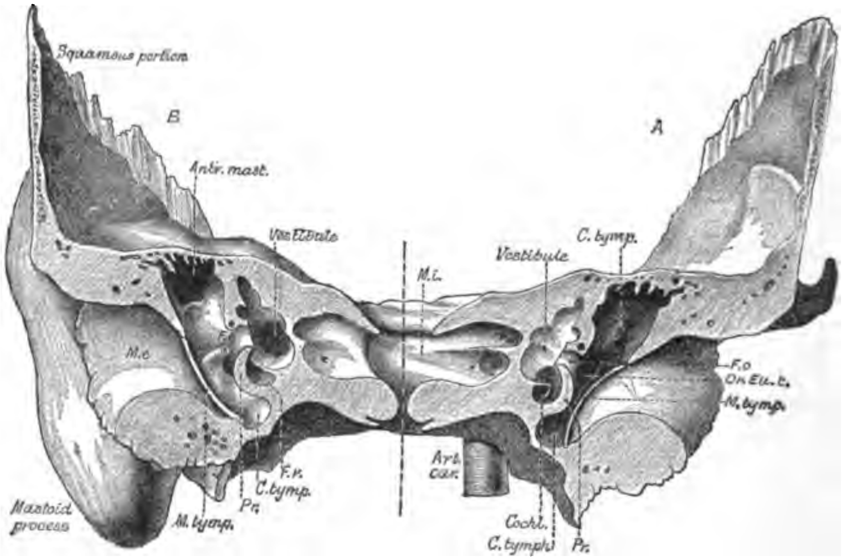


FIG. 220.—THE RIGHT TEMPORAL BONE SAWN IN A CORONAL PLANE THROUGH THE EXTERNAL AUDITORY MEATUS, TYMPANUM, VESTIBULE, AND INTERNAL AUDITORY MEATUS, THE POSTERIOR PART OF THE SAWN BONE (B) HAVING BEEN TURNED ROUND SO AS TO DISPLAY BOTH SURFACES OF THE SECTION. Natural size. (Testut.)

A, anterior aspect; *B*, posterior aspect.

TYMPANUM.—The cavum tympani is a narrow irregular chamber which may be described as bounded by a roof and floor, and mesial, lateral, anterior, and posterior walls. It is compressed from side to side, but the mesial and lateral walls are oblique, sloping from above downwards and inwards; the roof is broader than the floor, and the cavity diminishes in all directions towards its anterior end, where it becomes continuous with the Eustachian tube. Its greatest height, which is near the posterior wall, varies from 15 mm. to 20 mm., and the antero-posterior extent, measured from the tympanic orifice of the Eustachian tube to the opening into the mastoid antrum, is about 12 mm. to 15 mm. Its transverse diameter is smallest opposite the umbo of the membrana tympani, which is only about 2 mm. from the inner wall of the tympanum, and it is widest—6 mm. to 7 mm.—near the posterior part of the roof.

These measurements include the so-called *recessus epitympanicus*, *attic of the tympanum*, or *aditus ad antrum*, which is situated above the level of the tympanic membrane and lodges the head of the malleus and the greater part of the incus: this by Bezold and some other authors is excluded from the tympanum proper, which without it measures about 9 mm. In other words, the entrance to the mastoid antrum is about 9 mm. above the floor of the tympanic cavity. The orifice of the Eustachian tube is about 4 mm. above the lowest part of the floor.

The tympanum contains a chain of small bones, by means of which the vibrations communicated from without to the membrana tympani are conveyed across the cavity to the internal ear; and also certain minute muscles and ligaments which belong to the bones referred to, as well as nerves, some of which end within the cavity, while others merely pass through it to other parts. The cavity is otherwise filled with air, for it communicates with the atmosphere through the Eustachian tube, which leads into the pharynx. The bony walls of the cavity are by no means everywhere smooth, but marked in many situations with depressions, some deeper, others shallower, which are lined by a prolongation of the mucous membrane of the cavity and also contain air. These depressions are known as the *tympanic cells*.

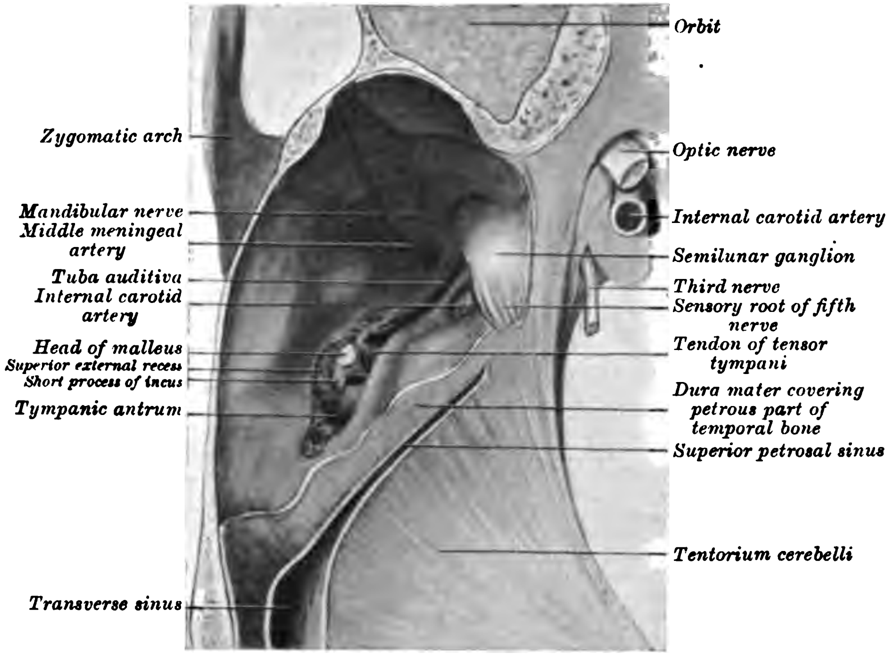

Orbit
Zygomatic arch
Optic nerve
Mandibular nerve
Middle meningeal artery
Internal carotid artery
Semilunar ganglion
Tuba auditiva
Third nerve
Internal carotid artery
Sensory root of fifth nerve
Head of malleus
Tendon of tensor tympani
Superior external recess
Short process of incus
Dura mater covering petrous part of temporal bone
Tympanic antrum
Superior petrosal sinus
Tentorium cerebelli
Transverse sinus

FIG. 221.—TUBA AUDITIVA, TYMPANIC CAVITY, AND TYMPANIC ANTRUM, EXPOSED FROM ABOVE. Natural size. (J. Symington.)

The **roof** of the tympanum is formed mainly by a thin plate of bone (*tegmen tympani*, fig. 224), which is seen in the fœtus to be an outgrowth from the petrous part of the temporal bone. This unites with a much narrower ridge projecting inwards from the squamous part of the temporal to form the petro-squamous suture. Traces of this suture can generally be detected in the adult, but as the petrous overlaps the squamous tegmen tympani, the upper or cerebral aspect of the suture is often a little external to the outer limit of the roof of the tympanum. The tegmen tympani also roofs over the mastoid antrum and the

Eustachian tube and canal for the tensor tympani, and in the whole of its extent slopes from behind obliquely downwards and forwards. It is not unfrequently partly deficient and may be easily broken through so as to obtain a view of the tympanic cavity from above (fig. 221).

The **floor** is narrow, in consequence of the outer and inner boundaries being inclined towards each other. It passes without any sharp demarcation into the anterior and posterior boundaries. It is separated by a thin plate of bone, which in rare cases is found to be incomplete, from the bulb of the internal jugular vein, and exhibits a small aperture through which the tympanic nerve reaches the inner wall.

The **lateral wall** is formed by the membrana tympani and the bony margin to which this membrane is attached. The osseous wall in front, below, and behind the membrana tympani is derived from the tympanic part of the temporal bone and above the membrane from the squamous portion. The lower edge of the squamosa is concave and completes the bony ring to which the tympanic membrane is attached. Above this notch the inner aspect of the squamosa presents a smooth area which forms the outer wall of the attic of the tympanum. Just internal to the anterior and upper part of the ring for the attachment of the membrana tympani is the inner end of a small canal (petro-tympanic) through which pass the chorda tympanic nerve and, in the fœtus, Meckel's cartilage.

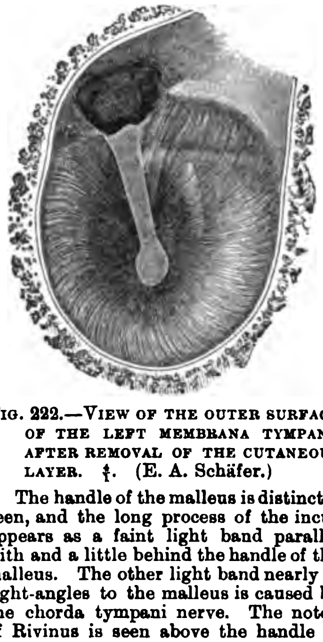


FIG. 222.—VIEW OF THE OUTER SURFACE OF THE LEFT MEMBRANA TYMPANI, AFTER REMOVAL OF THE CUTANEOUS LAYER. $\frac{4}{1}$. (E. A. Schäfer.)

The handle of the malleus is distinctly seen, and the long process of the incus appears as a faint light band parallel with and a little behind the handle of the malleus. The other light band nearly at right-angles to the malleus is caused by the chorda tympani nerve. The notch of Rivinus is seen above the handle of the malleus.

The **membrana tympani** is an ellipsoidal disc, the longer axis of which is directed from behind and above, forwards and downwards. It is about 10 mm. in its longer diameter, the shorter being about 9 mm. It is nearly as large at birth as in the adult. It is inserted into the groove already noticed at the end of the meatus externus, and so obliquely that the membrane inclines towards the anterior and lower part of the canal at an angle of about 55°. It is said to be more vertical in musicians and more horizontal in the congenitally deaf.[1] The handle of the malleus, one of the small bones of the tympanum, descends in contact with the inner surface of the membrana, covered by mucous membrane, to a little below the centre (*umbo*), where it is firmly fixed; and, as this process of the bone is directed inwards, the outer surface of the membrane is thereby depressed in a conical form (fig. 232). Above the handle the conical lateral process of the malleus bulges out the membrana tympani. If a line be prolonged downwards and backwards in the axis of the handle of the malleus to the lower end of the membrana tympani, and another be drawn at right-angles to this, opposite the umbo, the membrana tympani will be mapped out into four quadrants, of which the postero-superior is the largest and the antero-inferior the smallest.

The membrana tympani is about 0·1 mm. thick, but near its insertion into the sulcus tympanicus it becomes thickened and firmly attached to the bone by a considerable accumulation of fibres (*annulus fibrosus*), and this thickened margin is prolonged from the spines of the tympanic ring as two ligamentous bands which pass to the short process of the malleus, constituting the so-called *anterior and posterior tympano-malleolar folds or ligaments* (fig. 223), and forming the lower boundary of the pars flaccida of the tympanic membrane. Covering it externally is a prolongation of the skin of the external meatus; internally is a prolongation of the mucous membrane lining the cavity of the tympanum; and between the two is the proper substance of the membrane, composed of fibrous tissue in two layers. The greater number of the fibres radiate from the attachment of the handle of the malleus (fig. 222), but there are also circular fibres (fig. 226) which are on the tympanic side of the membrane; near but not quite at the circumference they form, as already stated, a dense thickening. Besides these two sets of fibres there are others met with, especially in the posterior half of the membrane, which are irregularly disposed and form at places prominent fibrous bands in and upon the tympanic surface of the membrane (covered of course by the mucous membrane). At the insertion of the malleus the membrane, especially its integumental layer, is thickened. The fibrous tunica propria here becomes continuous with the periosteum of the malleus, but along the line of contact of the bone with the membrane there is generally a streak of cartilage forming the actual uniting tissue: a similar thin layer of cartilage may also be found along the opposite (free) border of the manubrium mallei, and also forming a complete cap to the end of the manubrium. In the thickening of the integumental layer above mentioned vessels and nerves to the membrane are seen in section. The epidermal layer is stratified, as elsewhere in the external auditory meatus, but is much thinner and has no papillæ: it is somewhat thickened along the malleolar line, and here small papillæ of the cutis project into it. The radial fibres are not straight, but are slightly bowed outwards, so that between the most depressed point or *umbo*, and the attached border, the membrane is slightly convex outwardly. This shape is maintained by the annular fibres.

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[1] It is often described as being nearly horizontal in the fœtus and young infant, but Symington and Poirier found it to have about the same inclination as in the adult.

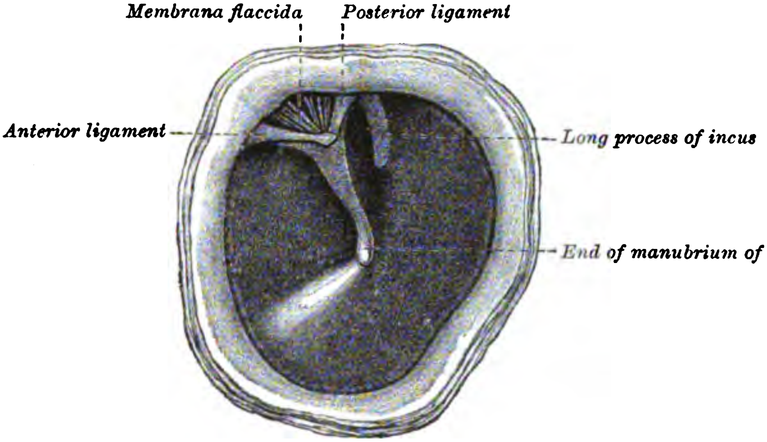

FIG. 223.—MEMBRANA TYMPANI, AS SEEN WITH THE OTOSCOPE. (Hensman.)

At the upper and anterior part, the annular fibres stretch, as just related, across the mouth of a small notch in the bony ring to which the membrane is attached (see p. 273). The notch is occupied by a lax membrane (*membrana flaccida*, Shrapnell) (fig. 223), consisting of loose connective tissue, with vessels and nerves, and covered by skin and mucous membrane. It occasionally happens that a fissure or perforation is to be detected at this place.

The membrane is supplied with blood-vessels, but they are chiefly confined to the skin and mucous membrane covering the surfaces: a few are, however, found in the proper fibrous membrane, and form a communication between the two systems on the surfaces. Those of the skin are mostly supplied by a small artery, derived from the deep auricular branch of the internal maxillary, which passes from above parallel to and along the handle of the malleus. The nerves for the most part accompany the blood-vessels, first supplying these and then forming a plexus both in the cutis and in the mucosa, under the epithelium of which they form flattened-out arborisations.[1] They are derived, for the anterior and greater part of the membrane, from the auriculo-temporal; for the posterior part, according to Sappey, from the auricular branch of the vagus. For the mucosa they come from the plexus tympanicus. Lymphatic vessels are, according to Kessel, tolerably abundant in all three layers.

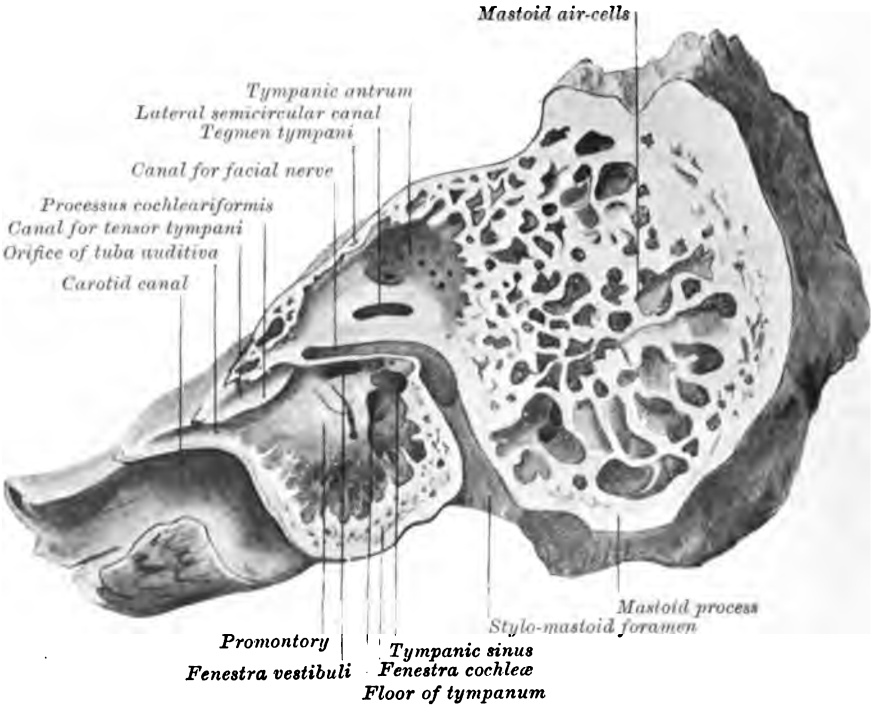
Mastoid air-cells
Tympanic antrum
Lateral semicircular canal
Tegmen tympani
Canal for facial nerve
Processus cochleariformis
Canal for tensor tympani
Orifice of tuba auditiva
Carotid canal
Mastoid process
Stylo-mastoid foramen
Promontory
Fenestra vestibuli
Tympanic sinus
Fenestra cochleæ
Floor of tympanum

FIG. 224.—SECTION OF THE TEMPORAL BONE OF AN ADULT SHOWING MASTOID AIR-CELLS AND THE MESIAL WALL OF TYMPANUM AND TYMPANIC ANTRUM. THE SECOND AND THIRD PORTIONS OF THE CANAL FOR THE FACIAL NERVE AND THE LATERAL SEMICIRCULAR CANAL HAVE BEEN OPENED. Natural size. (J. Symington.)

The **mesial wall** of the tympanum (fig. 224), which separates it from the internal ear, is very uneven. Near its upper part is an ovoid, or nearly kidney-shaped opening—*fenestra vestibuli* (*f. ovalis*), which leads into the cavity of the vestibule. This opening, which is elongated from before backwards, with a slight inclination downwards in front, is occupied in the recent state by the base of the stapes and the annular ligament connected with that plate of bone. It measures 3 mm. by 1½ mm., and lies at the bottom of a depression (*fossula*

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[1] Denicka, Arch. f. mikr. Anat. lxvi. 1905.

fenestræ vestibuli), which is bounded by the bony prominences immediately to be mentioned. Above the fenestra vestibuli, and between it and the roof of the tympanum, a ridge indicates the position of the facial canal, as it passes backwards, containing the facial nerve. This canal is separated from the tympanic cavity by a thin plate of bone. Below is a larger and more rounded elevation, caused by the projection outwards of the first turn of the cochlea, and named the *promontory*; its surface is marked by grooves, in which lie the nerves of the tympanic plexus.

Below and behind the promontory, and somewhat hidden by it, is another aperture named *fenestra cochleæ* (*f. rotunda*), 1·5 mm. to 2 mm. in diameter, which lies within a funnel-shaped depression (*fossula rotunda*). In the macerated and dried bone the fenestra cochleæ opens into the scala tympani of the cochlea; but, in the recent state, it is closed by a thin membrane.

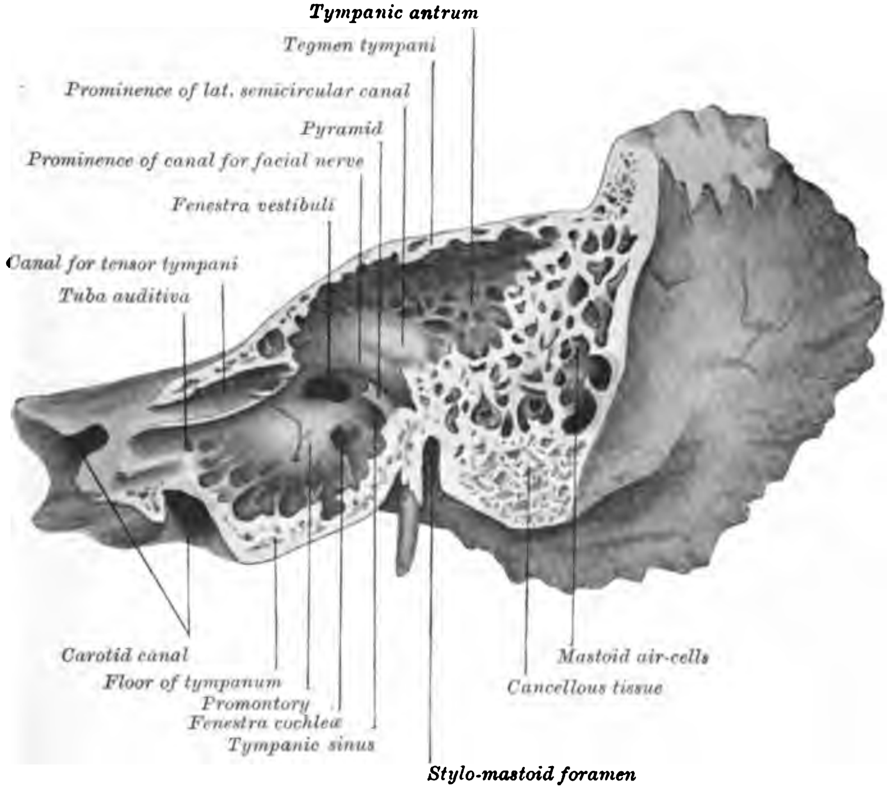
Tympanic antrum
Tegmen tympani
Prominence of lat. semicircular canal
Pyramid
Prominence of canal for facial nerve
Fenestra vestibuli
Canal for tensor tympani
Tuba auditiva
Carotid canal
Floor of tympanum
Promontory
Fenestra cochleæ
Tympanic sinus
Stylo-mastoid foramen
Mastoid air-cells
Cancellous tissue

FIG. 225.—SECTION OF THE LEFT TEMPORAL BONE OF A CHILD FIVE YEARS OLD. (J. Symington.)

The membrane closing the fenestra cochleæ—*secondary membrane of the tympanum*—is rather concave towards the tympanic cavity and convex to the scala tympani, and, like the membrana tympani, is composed of three structures, the middle being fibrous, and the outer and inner derived from the membranes lining the cavities between which it is interposed—viz. the tympanum and the cochlea. The membrane is not quite circular, but is prolonged superiorly and posteriorly into a somewhat triangular extension, which lies parallel and close to the lamina spiralis cochleæ, and forms an angle with the principal part of the membrane; the latter looks somewhat backwards and downwards, as well as outwards.

Another fossa is seen on the inner wall, behind the fossula rotunda and below the base of the pyramid. This fossa, which has been named the *sinus tympani*, is about 4 mm. in diameter and 3 mm. deep. The ampulla of the posterior semicircular canal lies close to its floor, and it is marked by one or two small apertures for vessels (Steinbrügge).

Below the promontory the inner wall presents the openings of numerous small air-cells, while above and behind the prominence of the canal for the facial nerve is a smooth convex surface which corresponds to the lateral semicircular canal. This surface extends backwards on the inner wall of the opening into the tympanic antrum.

The **posterior wall** of the tympanum has at its upper part a large opening which leads from the attic of the tympanum into the tympanic antrum. The orifice is usually triangular, with the base upwards and the inferior angle rounded, and has a diameter of 4 mm. to 6 mm.

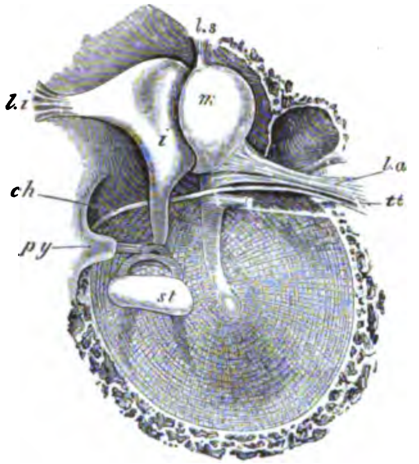

FIG. 226.—VIEW OF THE LEFT MEMBRANA TYMPANI AND AUDITORY OSSICLES FROM THE INNER SIDE, AND SOMEWHAT FROM ABOVE. $\frac{4}{1}$. (E. A. Schäfer.)

m, malleus; *i*, incus; *st*, stapes; *py*, pyramid, from which the tendon of the stapedius muscle is seen emerging; *t t*, tendon of the tensor tympani cut short near its insertion; *l.a*, anterior ligament of the malleus: the anterior process (processus gracilis) is concealed by the lower fibres of this ligament; *l.s*, superior ligament of the malleus; *l.i*, ligament of the incus; *ch*, chorda tympani nerve passing across the outer wall of the tympanum.

Below the orifice of the antrum and behind the fenestra vestibuli is a conical eminence (1 mm. to 1·5 mm. high), called the *pyramid* (fig. 226, *py*). Its apex is pierced by a foramen, through which the tendon of the stapedius muscle emerges. The muscle is contained within a canal which, when traced back, is found to turn downwards in the posterior wall of the tympanum, sometimes opening at the base of the cranium by a small aperture just in front of the stylomastoid foramen, and connected at one or two places with the descending part of the facial canal. A small bony spiculum often connects the end of the pyramid with the upper part of the promontory.

At the lower margin of the antral opening is a depressed surface (*fossa incudis*) where the short process of the incus is attached by ligamentous fibres to the tympanic wall, and close to the union of the outer and posterior walls is a small foramen for the passage of the chorda tympani nerve. Scattered over the posterior wall and most abundant near the opening into the antrum are the recesses of numerous tympanic air-cells, some of which may come into close relation with the descending part of the canal for the facial nerve.

Anterior wall.—The anterior extremity of the tympanum is narrowed by the gradual descent of the roof, and is continued into the inner orifice of the Eustachian tube (see diagram, fig. 201). Above the commencement of this is the small (2 mm. diameter) canal which lodges the tensor tympani muscle. This canal, which is lined by a fibrous membrane, is about half an inch (12 mm.) long, and it opens immediately in front of the fenestra vestibuli, surrounded by the expanded and everted end of the cochleariform process, which separates it from the Eustachian canal. The bony septum between the two canals is often incomplete, so that in the macerated bone they may appear as a single large canal partly subdivided by a thin osseous partition.

In the recent state the fibrous sheath of the tendon is expanded over the end of the canal, so as to impart to it a conical shape (see fig. 233, *tt*).

Below the orifice of the Eustachian tube the anterior wall is formed by a plate of bone which rises somewhat abruptly from the floor of the tympanum and separates the tympanic cavity from the vertical part of the carotid canal. The tympanic surface of this plate is covered with numerous small and usually simple air-cells, and these recesses are separated below from the carotid canal by a very thin plate of compact bone which is occasionally perforated.

SMALL BONES OF THE EAR.—Three small bones (*ossicula auditûs*) are contained in the upper part of the tympanum; of these, the outermost (*malleus*) is attached to the membrana tympani; the innermost (*stapes*) is fixed in the fenestra vestibuli; and the third (*incus*), placed between the other two, is connected to them by articular surfaces. They form together an angular and jointed connecting-rod between the membrana tympani and the fenestra vestibuli.

A

B

Magnified four times. (After Helmholtz.)

c, capitulum; *f*, groove beneath it; *a.i.*, articular surface for the incus; *e*, its lower margin; *d*, cervix; *m*, manubrium; *b*, processus lateralis; *a*, processus anterior, here represented only by a short stump, the rest of the process having been converted into ligament; *r*, ridge to which the external ligament is attached.

Magnified four times. (E. A. Schäfer.)

Most of the lettering is the same as in the previous figure. The processus anterior is here complete. The angle which the manubrium forms with the rest of the bone is seen in this view.

The **malleus** or hammer-bone (figs. 226 to 228) is 18 mm. to 19 mm. long, and weighs 24 milligr. It consists of an upper thicker portion, with a tapering lower portion, and two processes. The upper end is formed by the rounded *head* (*capitulum*) (*c*), on the posterior surface of which is an elliptical depressed surface (*a.i.*) with prominent margins, which passes obliquely downwards and inwards, and serves for articulation with the incus. The articular surface shows two principal facets, nearly at right-angles to one another. They are separated by a constriction and by an obliquely crossing crest or edge. These facets look, respectively, the upper and larger one backwards, the lower one inwards; and each principal facet is subdivided by a longitudinal groove into secondary facets. The inferior margin of the articular surface is very prominent opposite the constriction, and forms here, in fact, the lower end of the ridge above mentioned (*spur of the malleus*). Below the head is a constricted *neck* (*d*); and beneath this another slight enlargement of the bone, to which the processes are attached. The *handle* (*manubrium*) (*m*), the lower tapering point of the malleus, is slightly twisted, and is compressed from before backwards to near its point, where it is flattened laterally. Its direction forms an obtuse angle with that of the head of the bone (fig. 228), and passes downwards, with an inclination backwards and inwards, on the inner side of the membrana tympani, to which it is closely attached both by its periosteal covering and also by a layer of cartilage extending its whole length, and especially marked at the attachment of the processus brevis. The point of insertion of the tendon of the tensor tympani muscle is sometimes marked by a slight projection on the inner side of the manubrium near its upper end. The *anterior process* (fig. 228, *a*) is a very slender spiculum of bone, which in the adult is usually converted, except a small stump, into ligamentous tissue, and even where it still exists as bone is often broken off in its removal from the tympanum; it projects at nearly a right-angle from the front of the neck of the malleus, and extends thence obliquely downwards and forwards to the Glaserian fissure. Its end is flattened and expanded, and is connected by ligamentous fibres or bone to the sides of the fissure. In the fœtus this process is directly continued into Meckel's cartilage. The *lateral* (*short*) *process* (*b*) is a low conical eminence situated at the root of the manubrium, beneath the cervix, and projecting outwards towards the upper part of the membrana tympani, to which it is attached.

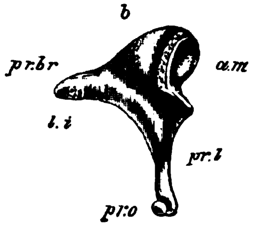

Fig. 229.—Left incus, viewed from the inner side and somewhat from before. Magnified four times. (G. D. Thane.)

b, body; *a.m*, ridged articular surface for the malleus; *pr.br*, processus brevis; *l.i*, rough surface near its extremity for the attachment of the ligament of the incus; *pr.l*, processus longus, terminating below in a small projection which comes off from it at a right-angle, and is capped by a convex tubercle, processus lenticularis, *pr.o*, for articulation with the stapes.

The **incus** (fig. 229), as its name implies, has been compared to an anvil; it resembles perhaps more nearly a bicuspid tooth with two fangs widely separated. It consists of a body and two processes. The *body* has a deep saddle-shaped articular surface in front (*a.m*), which fits over the articular surface on the head of the malleus, and which consists, like that of the malleus, of two chief facets, each subdivided to form two secondary facets. The lower margin of the articulation is excavated to receive the spur-like prominence of the malleus, and in front of this excavation is very prominent, where it also forms a spur, against which that of the malleus catches in inward movements of the manubrium. The *shorter process* (*crus breve*) (*pr.br*) of the incus projects backwards. Its extremity is tipped with cartilage, and is movably articulated by ligamentous fibres with the posterior and partly with the outer wall of the tympanum below the entrance to the tympanic antrum. The place where the ligamentous fibres are attached to the wall of the tympanum is somewhat depressed, and has a covering of cartilage. The *long process* (*crus longum*) (*pr.l*) tapers rather more gradually, and passes downwards and inwards parallel to the handle of the malleus, and about 1½ mm. mesial to and behind it. At its extremity it is bent inwards at an angle which varies considerably in different bones, and is suddenly narrowed into a short neck; and upon this is set a flattened tubercle (*processus lenticularis*) (*pr.o*), tipped with cartilage. This tubercle, which articulates with the head of the stapes, was formerly, under the name of *os orbiculare* seu *lenticulare*, described as a separate bone, which indeed it originally is in the fœtus up to the sixth month.

The length of the short process is 3 to 3½ mm., of the long process about 4½ mm. The weight of the incus is very nearly the same as that of the malleus (Blake).

At the joints between the incus and malleus on the one hand and the incus and stapes on the other the articular surfaces are tipped with cartilage and enclosed by a synovial membrane. Rüdinger describes, both in this joint and in the articulation of the incus with the stapes, an interarticular fibro-cartilage which subdivides the joint into two parts; but according to Brunner neither are synovial joints, but are symphyses, the articular cartilages being united by fibrous tissue. At all events, the existence of an interarticular cartilage at the joint between incus and stapes is doubtful, although most authorities admit its presence at the joint between the malleus and incus. Some anatomists describe a synovial joint at the articulation of the short process of the incus with the bone below the entrance to the tympanic antrum.

The **stapes** (figs. 226, 230), the third and innermost bone of the ear, is in shape remarkably like a stirrup, and is composed of a head, a base, and two crura. The whole bone measures 3 to 4 mm. in length and about 2½ mm. in breadth. Its weight is from 2 to 4 milligr. The *head* (*h*) is directed outwards, and has on its end a slight depression, covered with cartilage, which articulates with the lenticular process of the incus. The *base* (*b*) is a plate of bone fitting into the fenestra vestibuli, but not quite closely, so that a slight amount of movement is allowed. Its form is irregularly oval, the upper margin being curved, while the lower is nearly straight (fig. 226, *st*). Its border is encircled by hyaline cartilage, which also covers its vestibular surface. The margin of the fenestra vestibuli has also a covering of the same tissue (Toynbee), and the opposed cartilaginous surfaces are closely connected by a network of elastic fibres passing between them, and forming an especially dense ligamentous band near the tympanic and vestibular cavities (Rüdinger). The crura of the stapes diverge from a constricted part (*neck*, fig. 230, *c*) of the bone, situated close to the head, and are attached to the outer surface of the base near its extremities. The anterior crus (*cr.a*) is the shorter and straighter of the two. The crura, with the base of the stapes, encircle a small triangular space (*a*), across which in the recent state a thin membrane is stretched. A shallow groove runs round the opposed surfaces of the arch, and into this the membrane is received.

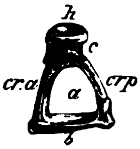

FIG. 230.—LEFT STAPES, VIEWED FROM BELOW. Magnified four times. (E. A. Schäfer.)

h, outer extremity or head of the bone, with a shallow concavity for articulation with the orbicular process of the incus; *c*, constricted part or cervix. This is not always so well-marked as in the present specimen. *cr.a*, anterior crus; *cr.p*, posterior crus; *b*, base; *a*, arch of the stapes. The bony groove which bounds the arch is shown in front and below; above and behind it is concealed from view.

The formation and morphological relations of the auditory ossicles have already been noticed under Embryology (Vol. I.). Suffice it here to recall the fact that the incus and malleus are originally laid down as one piece of cartilage, which is continued forwards as Meckel's cartilage along the first visceral arch, and that the stapes is formed by ossification in cartilage which develops around an artery (stapedial or mandibular)—(Fraser, Salensky)—which arises from the internal carotid, and passing into the tympanum through the wall of the carotid canal, ascends over the promontory and anastomoses with branches of the stylo-mastoid, middle meningeal, and ascending pharyngeal arteries. In rare instances this artery remains, but it has usually disappeared before birth. In some animals (Cheiroptera, Insectivora, Rodentia) it persists in the adult. In these cartilaginous foundations of the auditory ossicles the formation of the individual bones occurs in the following manner: the separation and articulation between the malleus and incus appears in the third month of embryonic life; the cartilaginous continuity between the malleus and Meckel's cartilage disappears somewhat later, and its place is taken partly by ligamentous tissue (forming the anterior ligament of the

malleus and the accessory mesial ligament of the mandibular articulation) and partly by a thin slip of membrane bone which develops in the perichondrium, and becomes the anterior process of the malleus. Besides this the malleus has two ossification centres—one in the head, the other in the manubrium—which appear at the end of the third or the beginning of the fourth month. About the same time an ossification-centre appears in the body of the incus, and from this the whole of the bone is formed, except the lenticular process, which appears as an epiphysis. The stapes ossifies somewhat later than the other ossicles, and from four centres—one for the head, one for each crus, and one for the base.

Ligaments.—In the articulations of the small bones of the ear with one another the connexion is strengthened by ligamentous fibres.

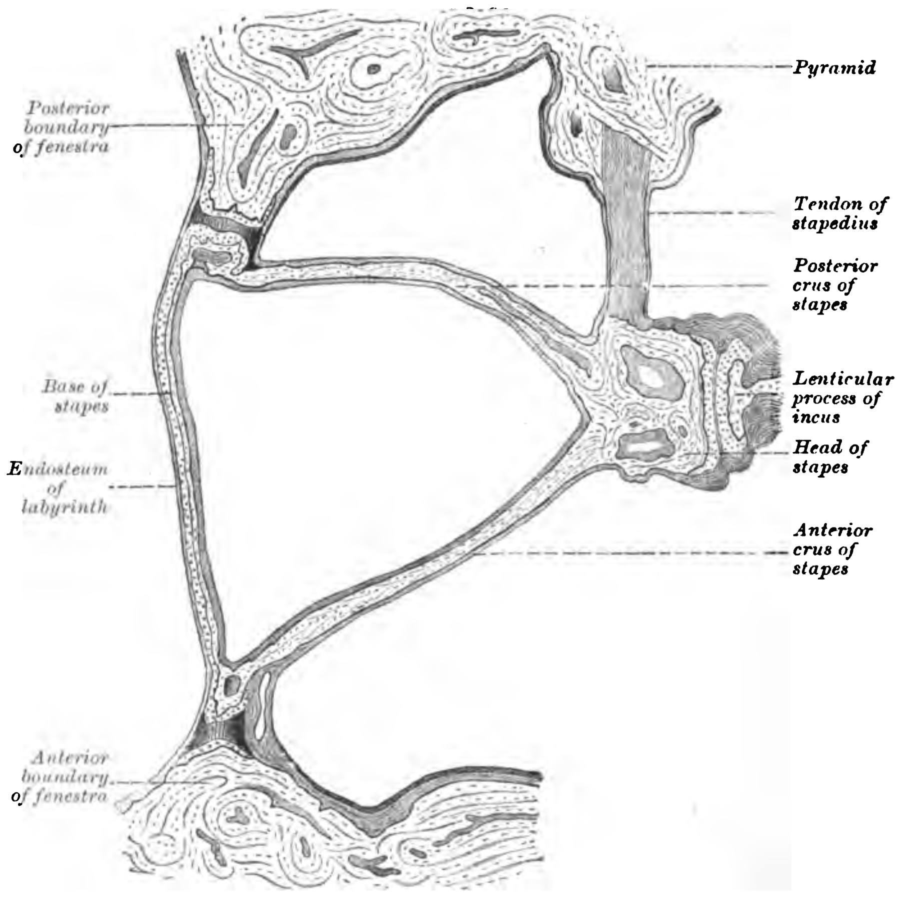
Pyramid
Posterior boundary of fenestra
Tendon of stapedius
Posterior crus of stapes
Lenticular process of incus
Base of stapes
Head of stapes
Endosteum of labyrinth
Anterior crus of stapes
Anterior boundary of fenestra

FIG. 231.—SECTION THROUGH STAPES AND FENESTRA VESTIBULI. (Brunner.)

Their attachment to the walls of the tympanum is effected chiefly by the following ligaments, as well as by the reflections of the mucous membrane lining that cavity.

The *anterior ligament of the malleus* (figs. 226, *l.a*, and 233, *l.a.m*) is a comparatively strong and broad band of fibres, which connects the base of the anterior process and the anterior part of the malleus above this process with the anterior wall of the tympanum close to the Glaserian fissure. The part of the ligament which passes out of the Glaserian fissure was long thought to be muscular (laxator tympani auct.), but all observers now agree in denying the existence of muscular tissue in this situation. Many of the fibres of the anterior ligament take origin from a bony prominence which projects from the margin of the external meatus into the tympanum, and forms the anterior boundary of the notch of Rivinus. This prominence is known as the anterior spinous process of the tympanum (spina tympanica anterior) (fig. 233, *sp*) to distinguish it from another smaller bony prominence or spine at the posterior extremity of the notch.

Accessory anterior ligament.—A comparatively stout sheath surrounds the tendon of the tensor tympani as it passes from the end of the cochleariform process to the malleus, and a flat ligamentous band with a thickened margin (fig. 233, *l*), which lies along the anterior border of this sheath, stretching between the anterior wall of the tympanum and the upper part of the manubrium and neck of the malleus, may be regarded as assisting in the fixation of the malleus anteriorly. Toynbee described the sheath in question as acting as an accessory ligament (tensor ligament).

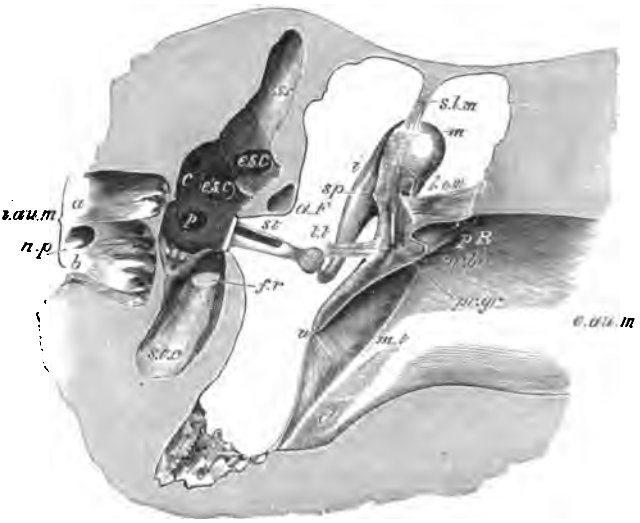

FIG. 232.—PROFILE VIEW OF THE LEFT MEMBRANA TYMPANI AND AUDITORY OSSICLES FROM BEFORE AND SOMEWHAT FROM ABOVE. Magnified four times. (E. A. Schäfer.)

The anterior half of the membrane has been cut away by an oblique slice. *m*, head of the malleus; *sp*, spur-like projection of the lower border of its articular surface; *pr.br*, its lateral process; *pr.gr*, root of processus anterior, cut; *s.l.m*, suspensory ligament of the malleus; *l.e.m*, its lateral ligament; *t.t*, tendon of the tensor tympani, cut; *i*, incus, its long process; *st*, stapes in fenestra vestibuli; *e.au.m*, external auditory meatus; *p.R*, notch of Rivinus; *m.t*, membrana tympani; *u*, its most depressed point or umbo; *d*, declivity at the extremity of the external meatus; *i.au.m*, internal auditory meatus; *a* and *b*, its upper and lower divisions for the corresponding parts of the acoustic nerve; *n.p*, canal for the nerve to the ampulla of the posterior semicircular canal; *s.s.c*, ampullary end of the superior canal; *p*, ampullary opening of the posterior canal; *c*, common aperture of the superior and posterior canals; *e.s.c*, ampullary, and *e'.s.c*, non-ampullary end of the lateral canal; *s.t.c*, scala tympani cochleæ; *f.r*, fenestra cochleæ, closed by its membrane; *a.F*, canalis facialis (aqueductus Fallopii).

The *lateral ligament of the malleus* (fig. 233, *l.e.m.*) is a fan-shaped ligamentous structure, the fibres of which arise from the margin of the notch of Rivinus, and converge to the lateral process and adjacent part of the malleus.

The posterior bundle of fibres of this ligament, together with the anterior bundle of the anterior ligament, are termed by Helmholtz the 'axis-ligament of the malleus,' since they are attached nearly in the axis of rotation of that bone.

The *superior ligament of the malleus* (figs. 226, 232, *s.l.m.*) consists of a small bundle of fibres, which passes downwards and outwards from the roof of the tympanum to the head of the malleus, and serves to check the outward movements of the manubrium and membrana tympani.

Inferior ligament of the malleus.—A small bundle of ligamentous fibres is occasionally found passing from near the extremity of the handle of the malleus upwards and backwards behind the long process of the incus, to be attached to the lateral wall of the tympanum. This ligament assists the lateral ligament in resisting a too violent action of the tensor tympani muscle, and it serves also to restrict any rotating action which that muscle may tend to exert upon the malleus.

The *ligament of the incus* (figs. 226, 233, *l.i.*) extends from near the point of the short crus backwards towards the posterior wall of the tympanum, but some of its fibres spread also outwards and inwards. It is attached below the entrance to the tympanic antrum.

Muscles.—There are only two well-determined muscles of the tympanum. Sömmerring described four, and some authors have mentioned a larger number; but their descriptions have not been confirmed by later research. Of the two muscles generally recognised, one is attached to the malleus and the other to the stapes.

The **tensor tympani** is the larger of these muscles. It consists of a tapering fleshy part, about half an inch in length, and a slender tendon. The muscular fibres arise from the cartilaginous end of the Eustachian tube and the adjoining surface of the sphenoid bone, and from the sides of the canal in which the muscle lies and in which it is conducted backwards to the cavity of the tympanum. Immediately in front of the fenestra vestibuli the tendon of the muscle bends at nearly a right-angle over the end of the processus cochleariformis as round a pulley, and, contained in a fibrous sheath, passes outwards to be inserted into the inner part of the handle of the malleus, close to its root (figs. 232, 233, *t.t*). The tensor tympani is supplied by a branch of the fifth nerve through the otic ganglion. Its nerve is furnished with a small ganglion (Dastre and Morat).

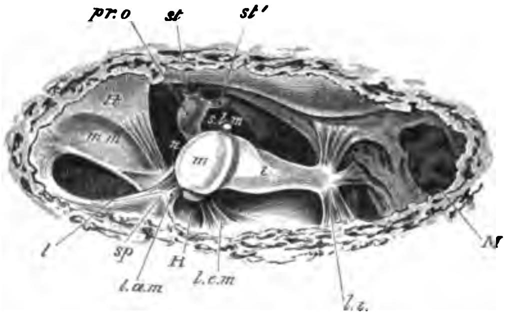

FIG. 233.—VIEW OF THE CAVITY OF THE TYMPANUM, OPENED FROM ABOVE. (Magnified four times.) (E. A. Schäfer).

m, head of the malleus; *sp*, spina tympanica anterior; *l.a.m*, anterior ligament of the malleus; *l.e.m*, lateral ligament of the malleus; *R*, gap between the two ligaments leading to the membrana flaccida and notch of Rivinus; *i*, body of the incus; *l.i*, posterior ligament of the incus; *pr.o*, processus orbicularis of the incus seen in the depth of the cavity, articulated with the head of the stapes, *st*; *st'*, tendon of the stapedius muscle emerging from the pyramid; *tt*, tendon of the tensor tympani, emerging from the conical end of its canal; *l*, thickened edge of a flattened band of ligamentous fibres which lies in the fold of the mucous membrane, *m.m*, and assists in fixing the malleus; *s.l.m*, superior ligament of the malleus, cut short; *n*, chorda tympani nerve.

The **stapedius** is a very distinct muscle, but is hidden within the bone, being lodged in a canal in front of the descending part of the facial canal and in the hollow of the pyramid. The tendon issues from the aperture at the apex of that little elevation (fig. 226), and, passing forwards, surrounded by a fibrous sheath, is inserted into the neck of the stapes posteriorly, close to the articulation of that bone with the lenticular process of the incus (figs. 231, 233).

A very slender spine of bone has been found occasionally in the tendon of the stapedius in man. A similar piece of bone, though of a rounder shape, exists constantly in the horse, the ox, and other animals.

Movements of the auditory ossicles.—The malleus and incus move together round an axis extending backwards from the attachment of the malleus by its anterior ligament to the attachment of the short process of the incus posteriorly. The handle of the malleus follows all the movements of the membrana tympani, and when the membrane is impelled inwards, the long process of the incus, moving inwards along with the malleus, pushes the stapes inwards towards the internal ear. In this movement the head of the stapes is slightly raised as well as pressed inwards, and the upper margin of its base moves more than the lower. But the cavity of the inner ear is full of liquid; and its walls are unyielding, except at the fenestra cochleæ; when, therefore, the stapes is pushed inwards, the secondary membrane of the tympanum which blocks up the fenestra cochleæ, must be bulged outwards. When the membrana tympani returns to its original condition these movements are reversed. That the movement inwards of the incus must closely accompany that of the malleus is necessitated by the fact that the lower margin of its articular surface has a well-marked projection which catches against the prominent border of the articular surface of the malleus (fig. 232, *sp*, and fig. 234). If, however, in consequence of increase of tension of the air in the tympanum, the malleus should be moved too freely outwards, the incus need not follow that movement to its full extent, but may merely glide over the smooth adjoining surface of the malleus, and thus the danger that there would otherwise be of forcibly dragging out the stapes from the fenestra vestibuli is avoided (Helmholtz).

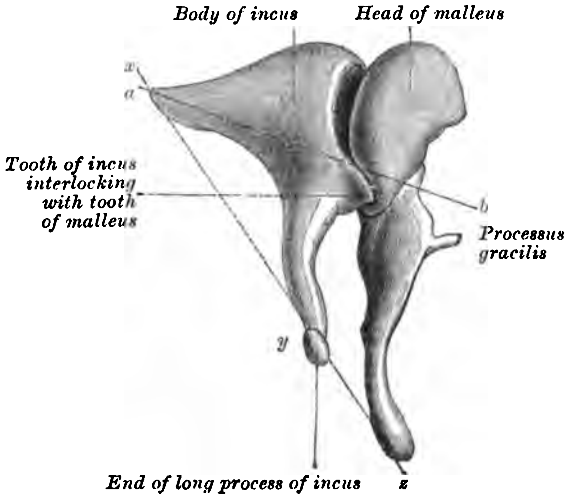
Body of incus
Head of malleus
x
a
Tooth of incus interlocking with tooth of malleus
b
Processus gracilis
y
End of long process of incus
z

FIG. 234.—FIGURE TO SHOW THE INTERLOCKING OF THE MALLEUS AND INCUS. (Helmholtz.)
The line *a b* indicates the axis of rotation of the two bones; the line *x y z* joins this axis with the two ends of the crank lever which these bones form.

The tensor tympani muscle, being attached near the base of the manubrium of the malleus, draws the whole bone and the membrane inwards, tightening the latter. Its action is opposed by the strong lateral ligament of the malleus. The tensor tympani exerts but little rotating action upon the malleus. The action of the stapedius muscle is obviously to draw the head of the stapes backwards, in doing which the hinder end of the base of that bone will be pressed against the margin of the fenestra vestibuli, while the fore-part will be withdrawn from the fenestra.

The lining membrane of the tympanum.—The mucous membrane of the tympanum is continuous with that of the pharynx through the Eustachian tube, and is further prolonged from the tympanum backwards into the tympanic antrum. The malleus and incus are invested by the lining membrane of the lateral wall of the cavity. The membrane forms also folds extending down from the roof in front of and behind the conjoined heads of the incus and malleus, and another passing down to the chorda tympani nerve or even below it; these folds wholly or partially separate off small pouch-like portions of the tympanic cavity, which will be further noticed below. Another well-marked fold has been already noticed in connexion with the tendon of the tensor tympani; and various other smaller folds are met with. They often contain strands of fibrous tissue and sometimes osseous spicules. All these folds are, however, very variable in their development.

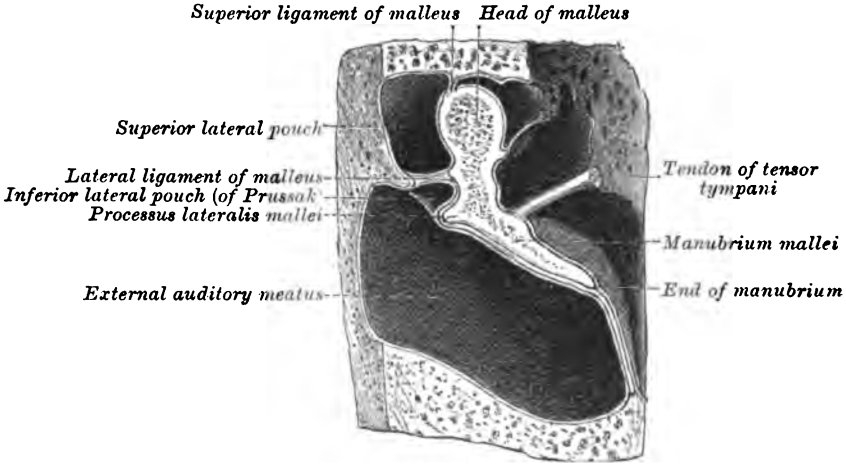

FIG. 235.—SECTION THROUGH THE MALLEUS AND MEMBRANA TYMPANI, SHOWING SOME OF THE POUCHES OR RECESSES OF THE TYMPANIC CAVITY. (After Merkel.)

The mucous membrane which lines the cartilaginous part of the Eustachian tube resembles much the membrane of the pharynx, with which it is immediately continuous; it is thick and vascular, is covered by ciliated epithelium, and is provided with many simple mucous glands which pour out a thick secretion: in the osseous part of the tube, however, the membrane becomes gradually thinner. In the tympanum and the mastoid cells the mucous membrane is paler, thinner, and less vascular, and secretes a small amount of less viscid, yellowish fluid. According to most observers, no glands are normally met with in the tympanum, but Krause has described and figured simple glands in parts, and Tröltsch described an acinous gland on the lateral wall, anteriorly. Between the mucous membrane and the periosteum is a network of fibrous bundles, which are here and there raised above the general surface, causing corresponding projections of the mucous membrane. In various places on the interlacing bundles, peculiar swellings occur of various sizes, which appear to be caused by the superaddition of concentrically arranged fibres upon the smaller bundles, producing an appearance similar to that of miniature Pacinian corpuscles (Politzer, Kessel).

The epithelium in the tympanic cavity is in part columnar and ciliated, with small cells between the bases of the ciliated cells, but the promontory, the ossicula, and the membrana are covered with a simple layer of flattened non-ciliated cells (Kölliker); and a similar non-ciliated epithelium lines the tympanic antrum and cells.

Recesses or pouches of the tympanum.—The ossicula, as well as the ligaments which unite them with the wall of the tympanum, and the chorda tympani nerve, are all invested by folds of the lining mucous membrane, which in many cases also pass across the spaces between the several ligaments and bony projections. These uniting folds and the prominences which they cover and connect thus mark off in certain places pouch-like portions of the general cavity. There is a good deal of variation in the extent of development of these folds and pouches, but some are fairly constant in their occurrence. One pouch is situated between the heads of the malleus and incus, and the lateral wall is bounded above by the thin tegmen tympani. It may be termed the *superior lateral pouch.* Immediately below it, and partly separated from it by the anterior and lateral ligaments of the malleus and a fold of membrane which unites them, is another smaller pouch, described by Prussak, which may be termed the *inferior lateral.* It is bounded above by the ligaments and folds just mentioned, externally by the membrana flaccida, below and internally by the processus brevis mallei. In front it ends blindly, but behind it opens into the general cavity of the tympanum. This pouch is of considerable importance clinically and pathologically because fluid may accumulate in it, especially since its opening into the rest of the posterior pouch is placed somewhat above its floor. It is into this pouch that perforations of the membrana flaccida occur.

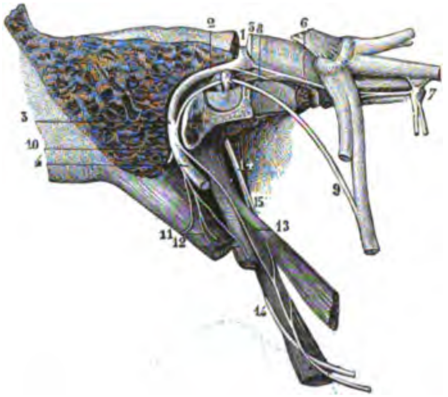

Fig. 236.—The facial nerve in its canal, with its connecting branches, etc. $\frac{3}{3}$. (From Sappey, after Hirschfeld and Leveillé.)

The mastoid and a part of the petrous bone have been divided nearly vertically, and the canal of the facial nerve opened in its whole extent from the internal meatus to the stylomastoid foramen; the Vidian canal has also been opened from the outer side.

1, facial nerve in the first horizontal part of its course; 2, its second part turning backwards; 3, its vertical portion; 4, the nerve at its exit from the stylo-mastoid foramen; 5, geniculate ganglion; 6, large superficial petrosal nerve; 7, sphenopalatine ganglion; 8, small superficial petrosal nerve; 9, chorda tympani; 10, posterior auricular branch, cut short; 11, branch to the digastric muscle; 12, branch to the stylohyoid muscle; 13, twig uniting with the glossopharyngeal nerve (14 and 15).

The fold which passes along the lateral wall of the tympanic cavity internal to the neck of the malleus, and which encloses in or near its free border the chorda tympani nerve, also separates off two pouches—one in front of and the other behind the manubrium mallei, and both bounded externally by the membrana tympani. These pouches are the *anterior* and *posterior pouches* of Tröltsch. They communicate below freely with the general tympanic cavity, and according to Siebenmann the anterior always ends blindly above, while the posterior frequently communicates with Prussak's space.

In the fœtus the mucous membrane of the tympanum consists of a swollen gelatinous embryonic tissue which fills the cavity, leaving only an irregular cleft between its folds. Towards the end of intra-uterine life the membrane becomes gradually thinner and less gelatinous and the cleft enlarges, fluid accumulating within it. After birth this fluid becomes replaced by air, and the mucous membrane speedily acquires the thin fibrous character which it exhibits throughout life.

Vessels and nerves of tympanum.—The **arteries** of the tympanum, though very small, are numerous, and are derived from branches of the external carotid, and from the internal carotid.

The fore-part of the cavity is supplied chiefly by the *tympanic branch* of the internal maxillary, which enters by the fissure of Glaser. The back-part of the cavity, including the mastoid cells, receives its arteries from the *stylomastoid branch* of the posterior auricular artery, which is conducted to the tympanum by the facial canal. These two arteries form by their anastomosis a vascular circle round the margin of the membrana tympani. The smaller arteries of the tympanum are, the *petrosal branch* of the middle meningeal, which enters through the *hiatus Fallopii*, and branches through the bone *from the internal carotid* artery, furnished from that vessel whilst in the carotid canal.

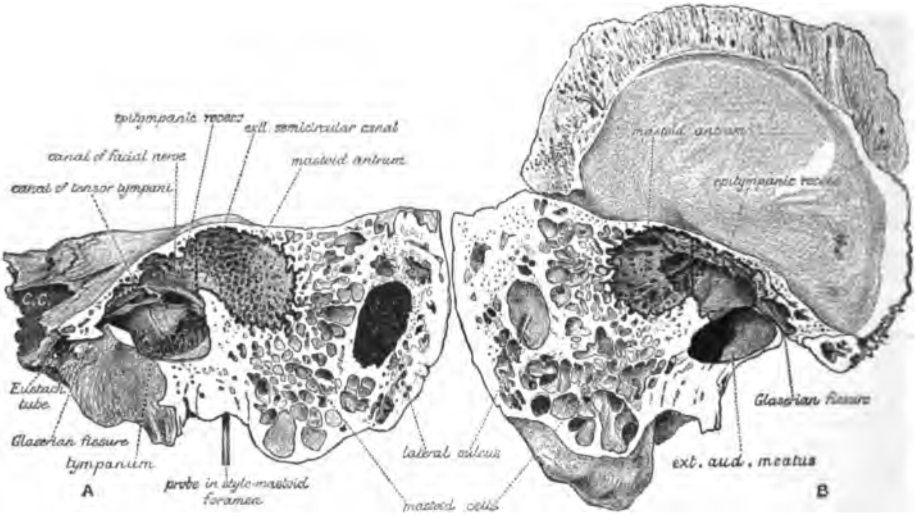
epitympanic recess
ext. semicircular canal
canal of facial nerve
mastoid antrum
canal of tensor tympani
C.C.
Eustach. tube
Glaserian fissure
tympanum
A
probe in stylo-mastoid foramen
lateral sulcus
mastoid cells
mastoid antrum
epitympanic recess
Glaserian fissure
ext. aud. meatus
B

FIG. 237.—LEFT TEMPORAL BONE, DIVIDED BY A VERTICAL SECTION PASSING THROUGH THE TYMPANUM AND TYMPANIC (MASTOID) ANTRUM: A, INNER PORTION; B, OUTER PORTION. Natural size (G. D. Thane.)

The section is directed somewhat obliquely from before, backwards and outwards. The tympanic cavity and the antrum are coloured blue, and the division between the epitympanic recess and the antrum is indicated by a dotted line; *c.c.* carotid canal.

The **veins** of the tympanum empty their contents into the superior petrosal sinus and the temporo-maxillary vein.

Nerves.—The tympanum contains numerous nerves; for, besides those which supply the parts of the middle ear itself, there are several which serve merely to connect nerves of different origin.

The lining membrane of the tympanum is supplied by filaments from the tympanic plexus, which occupies the shallow grooves on the mesial wall of the cavity, particularly on the surface of the promontory.

This plexus (fig. 236) is formed by (1) the *nerve of Jacobson* from the petrosal ganglion of the glossopharyngeal; (2) the *small deep petrosal nerve*, a filament connecting the nerve of Jacobson with the carotid plexus of the sympathetic; (3) a branch which joins the great superficial petrosal nerve; (4, and lastly) the *small superficial petrosal nerve*, passing to the otic ganglion.

Numerous ganglion-cells are found both in the uniting cords and also at the points of junction of the plexus.

The nerve of Jacobson or tympanic nerve enters the tympanum by a small foramen near its floor, which forms the upper end of a short canal in the petrous portion of the temporal bone, beginning at the base of the skull between the carotid foramen and the jugular fossa. The nerve connecting it with the carotid plexus is above and in front, and passes through the bone directly from the carotid canal. The branch to the great superficial petrosal nerve is lodged in a canal which opens on the mesial wall of the tympanum in front of the fenestra vestibuli. The small superficial petrosal nerve also leaves at the fore-part of the cavity beneath the canal for the tensor tympani.

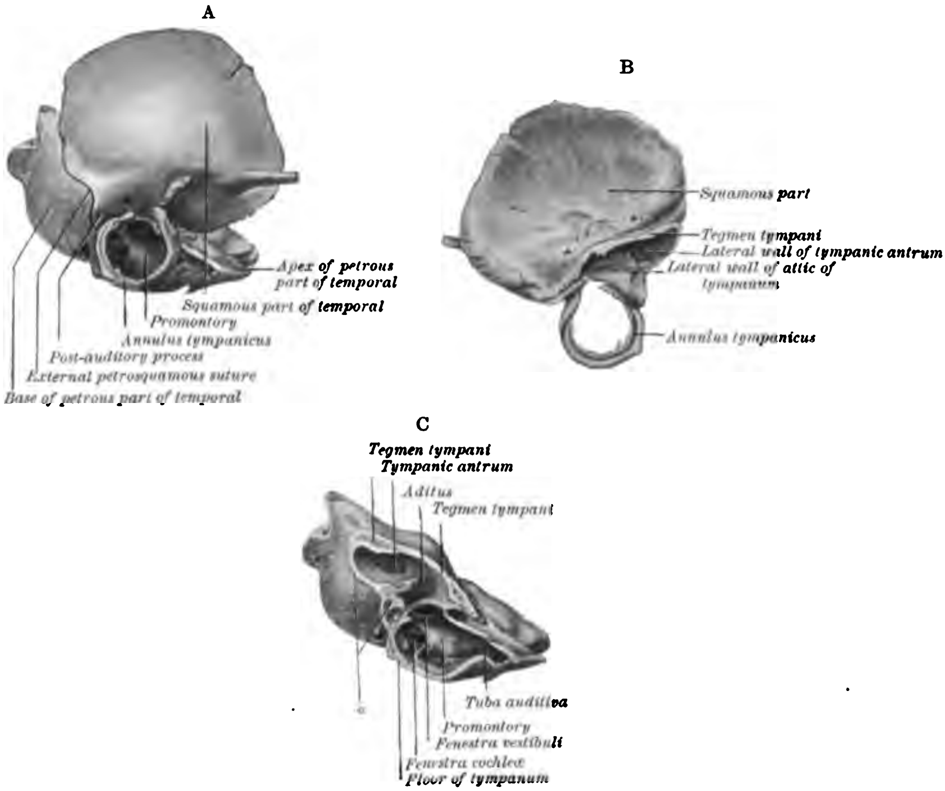
A
Apex of petrous part of temporal
Squamous part of temporal
Promontory
Annulus tympanicus
Post-auditory process
External petrosquamous suture
Base of petrous part of temporal
B
Squamous part
Tegmen tympani
Lateral wall of tympanic antrum
Lateral wall of attic of tympanum
Annulus tympanicus
C
Tegmen tympani
Tympanic antrum
Aditus
Tegmen tympani
*
Tuba auditiva
Promontory
Fenestra vestibuli
Fenestra cochleæ
Floor of tympanum

FIG. 238.—VIEWS OF THE RIGHT TEMPORAL BONE OF A NEWLY BORN INFANT. Natural size. (J. Symington.)

A, of the entire bone from the lateral aspect; B, of the squamous and tympanic portions from the mesial aspect; C, of the petrous portion from the lateral aspect with the squamous and tympanic portions removed; * surface which articulates with post-auditory process.

The tensor tympani muscle obtains its nerve from the internal pterygoid of the fifth through the otic ganglion; as already mentioned, its nerve is provided with a small ganglion. The stapedius receives filaments from the facial nerve.

The *chorda tympani*, arising from the facial near the lower end of the facial canal (aqueduct of Fallopius), takes a recurrent course to the tympanum, which it enters by an aperture in the posterior wall (*iter chordæ posterius*) just below the level of the pyramid. From this place it passes with a slight curve across the cavity near the outer boundary, and, crossing successively the posterior part of the membrana tympani, the handle of the malleus near its neck, and the anterior process of the same bone, finally enters a small canal (*iter chordæ anterius*) in the bone close to the Glaserian fissure. It is invested by the fold of the lining membrane already mentioned.

TYMPANIC ANTRUM AND MASTOID CELLS.—The tympanic antrum, generally termed the mastoid antrum, is an air-cavity of a somewhat oval form which communicates in front with the attic of the tympanum and extends backwards and outwards into the temporal bone, its main axis forming an angle of about 45° with that of the external auditory meatus. It varies very considerably in size, but on an average its antero-posterior extent is about 10 mm. to 12 mm., its height 8 mm. to 10 mm., and its breadth 6 mm. to 8 mm. Its posterior concave end is directed towards the outer part of the posterior surface of the petrous part of the temporal bone and the adjacent portion of the transverse sinus. The mesial wall is related in front to the lateral semicircular canal, and the roof is separated from the cranial cavity merely by the delicate tegmen tympani. All its walls are beset with air-cells, but the most extensive masses of cellulæ mastoideæ are related to the lateral wall and floor. The air-cells in its lateral wall separate it from the posterior wall of the external auditory meatus; those behind it extend backwards nearly to the transverse sinus; while below these cells may reach to the apex of the mastoid process.

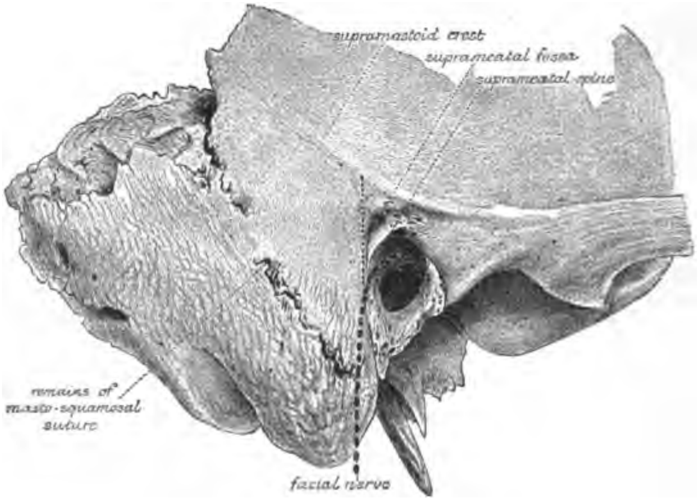

FIG. 239.—LOWER AND POSTERIOR PORTION OF RIGHT TEMPORAL BONE, SHOWING THE SUPRAMEATAL TRIANGLE, COURSE OF THE FACIAL NERVE, ETC. Natural size. (G. D. Thane.)

The middle ear in infancy and childhood.—At birth the Eustachian tube is about 17 mm. in length, or half that of the adult, and its direction is nearly horizontal, only ascending about 10° in its course from the pharynx to the tympanum. The pharyngeal orifice is small, without a prominent posterior lip, and lies slightly below the level of the hard palate, while the osseous wall of the tympanic end is imperfectly developed. During early childhood the tube grows rapidly, so that by the fifth year it is about 30 mm. long.

The tympanic cavity is nearly as large at birth as in the adult, and such is also the case with the auditory ossicles. The tympanic cavity is bounded at birth by the petrous, squamous, and tympanic portions of the temporal bone with their intervening sutures, but these sutures are partially obliterated during the first year. The mesial wall of the tympanum undergoes little, if any, change after birth, and the roof retains its thinness throughout life and its suture (internal petro-squamous) is seldom entirely obliterated. The lateral wall of the attic of the tympanum is greatly thickened by the formation of the bony roof of the external auditory meatus, so that instead of being bounded externally, as at birth, by a thin plate of bone, it is separated from the lateral aspect of the skull by a distance of 10 to 15 mm.

The tympanic antrum is a part of the primitive middle-ear cavity, is developed along with the tympanic cavity, and is generally fully as large at birth as in the adult. It is bounded at birth by the petrous part of the temporal bone except externally, where the thin post-auditory process of the squamosa is found. The suture uniting these two elements of the temporal bone is visible on both the cerebral and external aspects of the skull. Soon after birth the squamous and petrous elements begin to unite, but traces of the suture uniting them generally remain until adult life. At birth the tympanic antrum is separated from the lateral surface of the skull by a thin outer layer of compact bone and an inner layer of small air-cells. Below these air-cells the bone is densely diploëtic. The deposit of new bone on the lateral aspect of the temporal causes the tympanic antrum to become more deeply placed in relation to the lateral surface of the skull. The fine cancellous tissue thus formed is, as a rule, gradually replaced by air-cells, the lining of which is continuous directly or indirectly with that of the tympanic antrum. The period of life and the extent to which this pneumatisation occurs varies considerably in different individuals. The lateral antral wall is generally mainly diploëtic until about the fifth year, but numerous air-cells are usually formed by the tenth year, and may be present as early as the second year (A. H. Cheatle). Sometimes the diploëtic bone, instead of being converted into air-cells, undergoes to a greater or less extent a process of consolidation, forming the sclerosed mastoid.

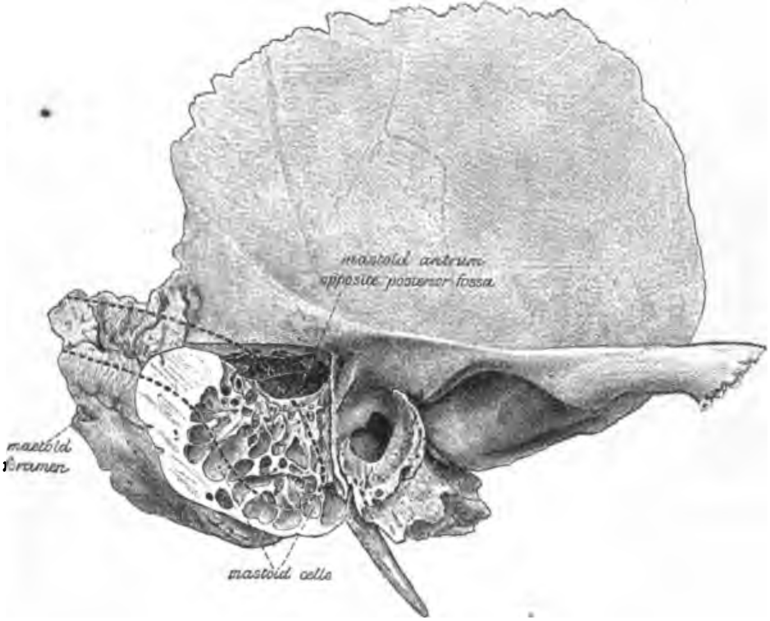

FIG. 240.—RIGHT TEMPORAL BONE, FROM WHICH THE SUPERFICIAL PORTION OF THE MASTOID DIVISION HAS BEEN REMOVED, EXPOSING THE TYMPANIC ANTRUM. Natural size. (G. D. Thane.)
The broken line indicates the position of the lateral sinus.

Surgical anatomy of the tympanic (mastoid) antrum.—The tympanic antrum may be reached from the exterior by perforating the bone close to the upper and posterior part of the external auditory meatus. In this region Macewen describes a *suprameatal triangle*,[1] which is bounded above by the supramastoid crest, below and in front by the postero-superior quadrant of the outer margin of the osseous meatus, and behind by a vertical line tangential to the hindmost point of that opening. The surface of bone included in the triangle is usually marked by a small depression—the *suprameatal fossa*, which is separated from the aperture of the meatus by a sharp prominent edge—the *suprameatal spine*. The perforation should be made within this area, at the site of, or close behind, the suprameatal fossa, and be directed inwards and slightly forwards, following the inclination of the external auditory meatus. The antrum will then be opened at its fore-part, at a depth from the surface varying generally from 7 to 14 mm.; in extreme cases, and especially as the result of disease, this distance may be reduced to 3 mm., or increased to 18 mm., or even more. At the lower part of the entrance into the antrum the mesial wall of the cavity presents a slight bulging over the lateral semicircular canal (fig. 237), which may be injured if the instrument is not checked as soon as the cavity is reached: the distance of the wall of the canal from the surface is mostly between 17 and 20 mm. (about three-quarters of an inch). Just below and in front of this, on the inner side of the epitympanic recess, is the arch of the facial nerve contained in its canal, the osseous wall of which is thin towards the cavity, and often defective in part. The nerve will best be avoided by not directing the perforation too much forwards. Between the semicircular canal in front and the lateral sinus behind, the air-spaces are in relation internally with the posterior fossa of the base of the skull, the thickness of the intervening bone ranging from 1 to 9 mm. The original perforation must be kept below the supramastoid crest in order to avoid opening

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[1] W. Macewen, 'Pyogenic Infective Diseases of the Brain and Spinal Cord,' 1893, p. 9.

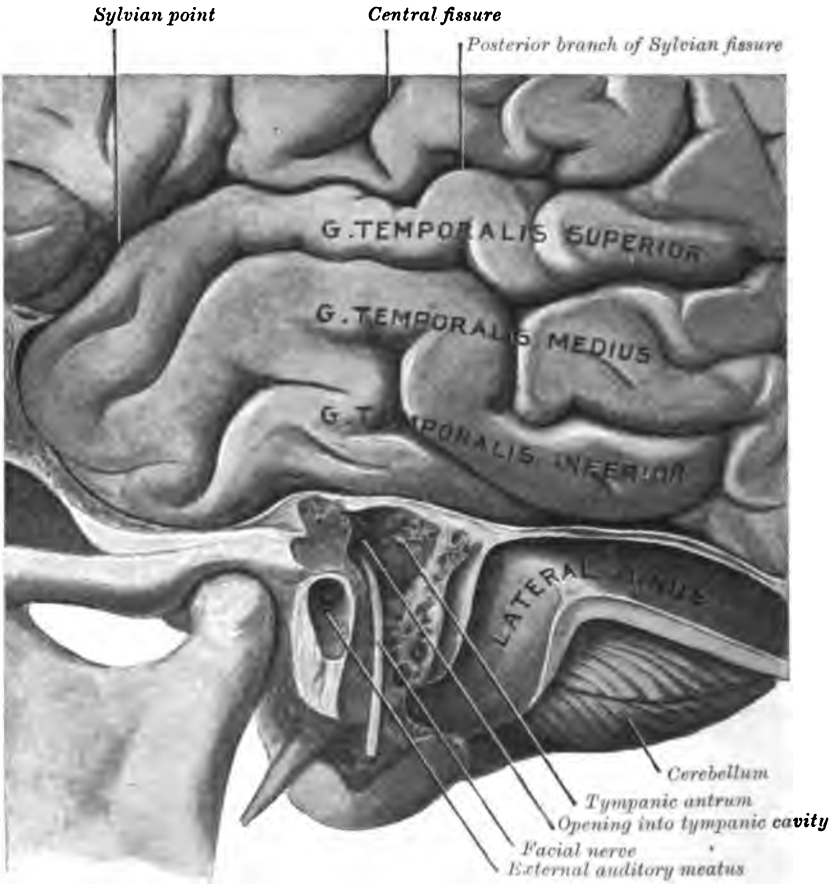
Sylvian point
Central fissure
Posterior branch of Sylvian fissure
G. TEMPORALIS SUPERIOR
G. TEMPORALIS MEDIUS
G. TEMPORALIS INFERIOR
LATERAL SINUS
Cerebellum
Tympanic antrum
Opening into tympanic cavity
Facial nerve
External auditory meatus

FIG. 241.—DISSECTION TO DISPLAY THE RELATIONS OF THE BRAIN, LATERAL SINUS, AND FACIAL NERVE TO THE TYMPANIC ANTRUM IN AN ADULT MALE. Natural size. (J. Symington.)

the middle fossa of the skull; and it should not extend backwards more than 2 mm. beyond the posterior boundary of the suprameatal triangle, or the lateral sinus may be endangered.

In the infant there is no suprameatal crest to indicate the upper limit of the tympanic antrum, and care must be taken in going above the level of the roof of the external auditory meatus. In consequence of the slight development of the mastoid process, the exit of the facial nerve is much more superficial than in the adult, and if the skin-incision behind the pinna be carried too far downwards and forwards the nerve is very liable to be injured.

The lateral wall of the antrum is relatively thinner than in the adult, but considerable differences will be found in children of the same age with respect to the density of the lateral antral wall.

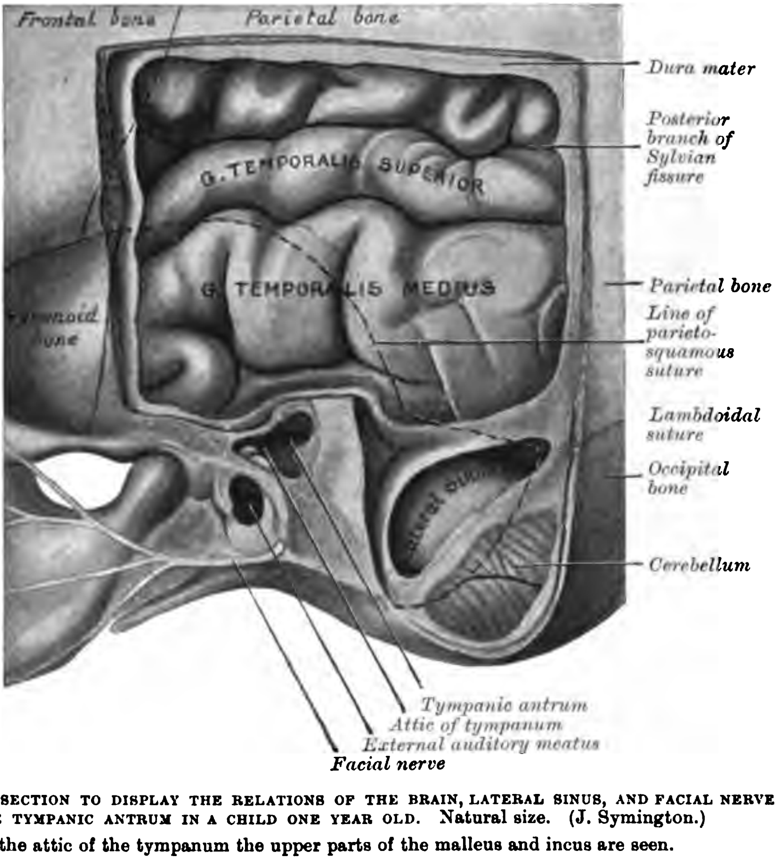
Frontal bone
Parietal bone
Dura mater
Posterior branch of Sylvian fissure
G. TEMPORALIS SUPERIOR
G. TEMPORALIS MEDIUS
noid bone
Parietal bone
Line of parieto-squamous suture
Lambdoidal suture
Occipital bone
lateral sinus
Cerebellum
Tympanic antrum
Attic of tympanum
External auditory meatus
Facial nerve

FIG. 242.—DISSECTION TO DISPLAY THE RELATIONS OF THE BRAIN, LATERAL SINUS, AND FACIAL NERVE TO THE TYMPANIC ANTRUM IN A CHILD ONE YEAR OLD. Natural size. (J. Symington.)

In the attic of the tympanum the upper parts of the malleus and incus are seen.

THE INTERNAL EAR, OR LABYRINTH.

The inner, essential part of the organ of hearing, is contained in the petrous portion of the temporal bone. It consists of a complex cavity—the osseous labyrinth—hollowed out of the bone, and containing the membranous labyrinth.

The *osseous labyrinth* is incompletely divided into three parts, named the vestibule, the semicircular canals, and the cochlea. They are lined throughout by a thin periosteal membrane, within which there is a clear fluid named perilymph, or liquor Cotunnii.

The *membranous labyrinth* being distinctly smaller than the bony labyrinth, a space is left between the two, occupied by the perilymph just referred to. The membranous structure is lined throughout by epithelium, and at certain parts receives branches of the auditory nerve. It contains a fluid named the endolymph, and consists of several parts—viz. the utricle, saccule, semicircular canals, and membranous cochlea.

THE OSSEOUS LABYRINTH.

The **vestibule** forms a central chamber of the labyrinth which communicates in front with the cochlea, behind with the semicircular canals, externally with the tympanum, and internally with the bottom of the internal auditory meatus. It is irregularly ovoidal in shape, measuring about 5 mm. from above down and from before back, but slightly less from without inwards.

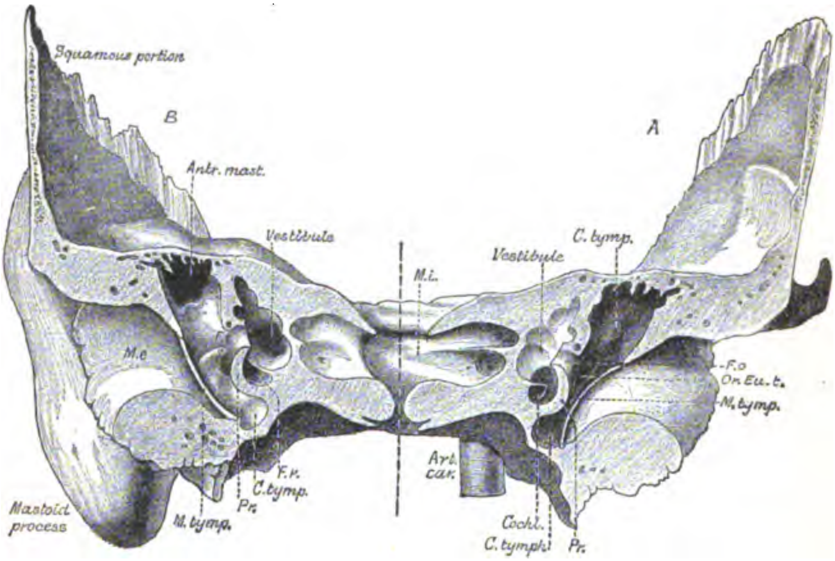

FIG. 243.—THE RIGHT TEMPORAL BONE SAWN ACROSS IN A CORONAL PLANE; THE CUT PASSING THROUGH THE FENESTRA VESTIBULI. Natural size. (Testut.)

A, anterior, B, posterior segment, showing the cut surfaces.

M.e., meatus externus; *M.tymp.*, groove for membrana tympani; *C.tymp.*, tympanic cavity; *Antr.mast.*, antrum mastoideum; *Pr.*, promontory; *Or.Eu.t.*, orifice of Eustachian tube; *F.o.*, fenestra vestibuli; *F.r.*, fenestra cochleæ; *Cochl.*, commencement of cochlea; *M.i.*, meatus audit. internus; *Art.car.*, internal carotid artery.

The lateral wall, which separates it from the cavity of the tympanum, is perforated by the fenestra vestibuli, which in the recent state is closed by the base of the stapes.

At the fore-part of the mesial wall is a small round pit, the *recessus sphæricus* (fig. 245, 2), pierced with many minute holes which serve to transmit branches of the acoustic nerve from the internal auditory meatus to the saccule. This fossa is limited behind by a vertical ridge named *crista vestibuli*, the upper extremity of which has been termed the *pyramid of the vestibule*, and merges on to the roof. The crista passes downwards on the mesial wall and bifurcates on the floor of the vestibule; the fork encloses a small fossa, which was termed *recessus cochlearis* by Reichert; it receives the beginning of the ductus cochlearis and is pierced with a number of holes for the passage of nerve-fibres. Behind the lower part of the crest is the small oblique groove which deepens into a fine canal, the *aqueduct of the vestibule* (fig. 245, 4). This extends to the posterior surface of the petrous bone and transmits the ductus endolymphaticus (p. 309) and a small vein.

Behind the crista vestibuli is a shallow elongated depression (*recessus ellipticus*) which extends from the roof down the inner wall to the floor. The crest and pyramid between these two depressions are pierced with fine holes for the passage of nerve-fibres, those in the crest itself being destined for the utricle; those in the pyramid for the ampullæ of the superior and lateral semicircular canals.

Towards the back part of the vestibule are five round apertures leading into the semicircular canals; and at the lower and outer part of the anterior end of the cavity is a larger opening which communicates with the scala vestibuli of the cochlea.

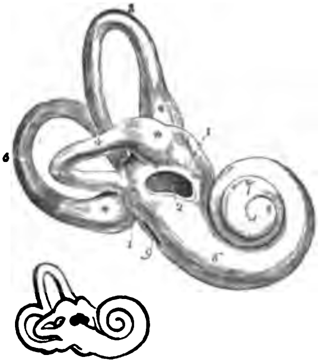

FIG. 244.—RIGHT BONY LABYRINTH, VIEWED FROM THE OUTER SIDE. Magnified 2½ diameters. (After Sömmerring.)

The specimen here represented is prepared by separating piecemeal the looser substance of the petrous bone from the dense walls which immediately enclose the labyrinth.

1, the vestibule; 2, fenestra vestibuli; 3, superior semicircular canal; 4, lateral canal; 5, posterior canal; * * *, ampullæ of the semicircular canals; 6, first turn of the cochlea; 7, second turn; 8, apex; 9, fenestra cochleæ. The smaller figure in outline below shows the natural size.

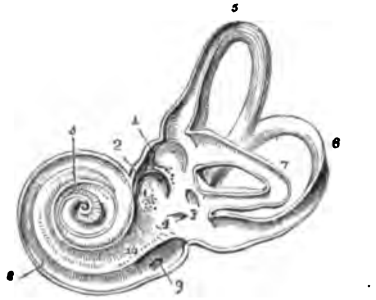

FIG. 245. — VIEW OF THE INTERIOR OF THE LEFT LABYRINTH. Magnified 2½ diameters. (From Sömmerring.)

The bony wall of the labyrinth is removed superiorly and externally.

1, recessus ellipticus; 2, recessus sphericus; 3, common opening of the superior and posterior semicircular canals; 4, opening of the aqueduct of the vestibule; 5, the superior, 6, the posterior, and 7, the lateral semicircular canals; 8, spiral tube of the cochlea (scala tympani); 9, opening of the aqueduct of the cochlea; 10, placed on the lamina spiralis in the scala vestibuli.

The **semicircular canals** are three tubes, situated above and behind the vestibule, into which they open by five apertures, the contiguous ends of two of the canals being joined. They are unequal in length, but each tube is bent so as to form about two-thirds of an ellipse, and is moreover dilated at one end, the enlargement being known as the *ampulla*. The canals are compressed laterally, and measure 1 mm. to 1·5 mm. across; but the ampulla has a diameter of about 2 mm.

The canals differ from one another in direction, in length, and in position with regard to the vestibule. The *superior semicircular canal* (fig. 244, 3; fig. 245, 5), 19 mm. long, is nearly vertical and lies transversely to the bony axis of the petrous bone, forming an angle of about 45° with the coronal plane; it rises higher than any other part of the labyrinth, and its place is indicated by a smooth arched projection on the upper surface of the petrous bone. The ampullary end of this canal is the lateral and anterior, and opens by a distinct orifice into the anterior part of the roof of the vestibule; whilst the opposite extremity joins the non-dilated end of the posterior semicircular canal, and opens by a common aperture with it into the posterior part of its roof (fig. 245, 3). The *posterior semicircular canal* (fig. 244, 5; fig. 245, 6) is also nearly vertical, and lies in a plane which is almost parallel with that of the superior canal of the other side (Mach, Crum Brown). The posterior and superior canals of the same side incline towards one another at their inner ends. The posterior is the longest of the three (22 mm.): its ampullary end is at the back part of the floor of the vestibule; and the opposite end terminates in the common canal above described. In its course this canal comes close to the sinus tympanicus of the tympanum. The *lateral semicircular canal* (fig. 244, 4; fig. 245, 7) arches *horizontally* outwards, and opens by two distinct orifices on the upper part of the lateral wall of the vestibule. The ampulla of this canal is at the anterior end, and its opening is just below the ampullary end of the superior canal and above the fenestra vestibuli. The posterior orifice is below the common opening of the superior and posterior canals. The lateral canal is shorter than the other two (15 mm.).

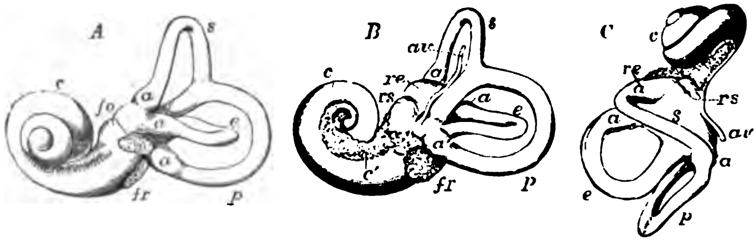

FIG. 246.—VIEWS OF A CAST OF THE INTERIOR OF THE LABYRINTH. $\frac{2}{1}$. (From Henle.)

Such casts may easily be made in fusible metal, and give a very correct view of the form of the different parts of the labyrinthic cavity.

A, view of the left labyrinth from the outer side; B, the right labyrinth from the inner side; C, the left labyrinth from above; *s*, the superior, *p*, the posterior, and *e*, the lateral semicircular canals; *a*, their several ampullæ; *re*, recessus ellipticus of the vestibule; *rs*, recessus sphericus; *av*, aqueduct of the vestibule; *fo*, fenestra vestibuli; *fr*, fenestra cochleæ; *c*, coiled tube of the cochlea; *c'*, tractus spiralis foraminosus.

The **cochlea** (figs. 244, 245), when cleared of the surrounding less dense bony substance in which it lies imbedded, appears in the form of a blunt cone, the base of which is turned towards the internal auditory meatus, whilst the apex is directed outwards, with an inclination forwards and downwards, and is close to the canal for the tensor tympani muscle. It measures about 5 mm. from base to apex, and 9 mm. in breadth at the base. It consists of a gradually tapering spiral tube, the inner wall of which is formed by a central column or *modiolus* (fig. 250), around which it winds. It is partially divided along its whole extent by a spiral lamina, projecting into it from the modiolus. From this osseous spiral lamina membranous structures are in the recent condition stretched across to the outer wall of the tube, and thus completely separate two passages or *scalæ*, one on each side of the spiral lamina, which communicate one with the other only by a small opening, named *helicotrema*, placed at the apex of the cochlea.

That the cochlea is justly to be considered as an elongated tube, coiled spirally on the modiolus, is illustrated by the simple pouch-like form of the rudimentary cochlea of birds as well as by the history of its development.

The *spiral osseous canal* is about 33 mm. long, and rather more than 2 mm. in diameter at the commencement, where it is widest. From this point the canal makes nearly two and three-quarter turns round the central pillar (from left to right in the right ear, and in the opposite direction in the left ear, supposing the cochlea viewed from the base), and ends by a domed extremity called the *cupola*, which forms the summit of the cochlea. The first coil, having by far the

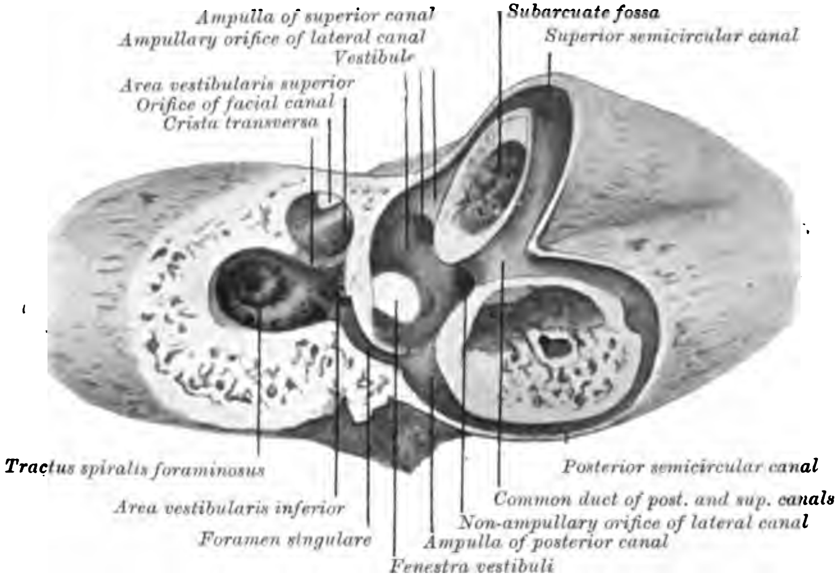
Ampulla of superior canal
Ampullary orifice of lateral canal
Vestibule
Area vestibularis superior
Orifice of facial canal
Crista transversa
Subarcuate fossa
Superior semicircular canal
Tractus spiralis foraminosus
Area vestibularis inferior
Foramen singulare
Fenestra vestibuli
Ampulla of posterior canal
Non-ampullary orifice of lateral canal
Common duct of post. and sup. canals
Posterior semicircular canal

FIG. 247.—THE RIGHT TEMPORAL BONE OF A NEWLY BORN INFANT. $\frac{4}{1}$. (J. Symington.)

The bone was filed away so as to expose the outer end of the internal auditory meatus, the vestibule, and the superior and posterior semicircular canals, and is viewed from above and from the mesial side.

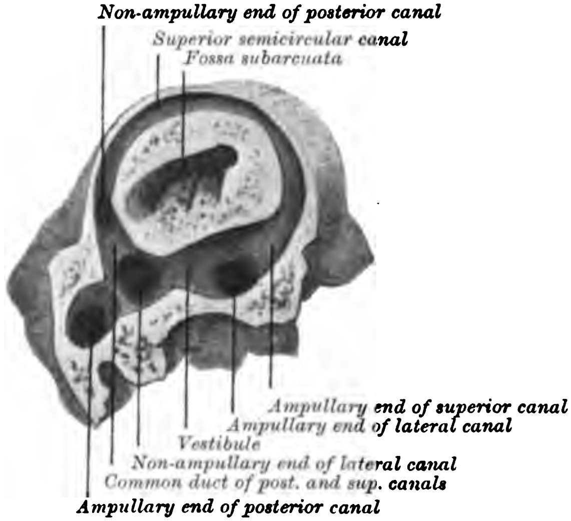
Non-ampullary end of posterior canal
Superior semicircular canal
Fossa subarcuata
Ampullary end of superior canal
Ampullary end of lateral canal
Vestibule
Non-ampullary end of lateral canal
Common duct of post. and sup. canals
Ampullary end of posterior canal

FIG. 248.—THE PETROUS PART OF THE LEFT TEMPORAL BONE OF A NEWLY BORN INFANT. $\frac{4}{1}$. (J. Symington.)

The bone was divided in the plane of the superior semicircular canal and is viewed from the front and from the mesial side.

most extensive curve and being the largest portion of the tube, nearly hides the second from view; and, bulging somewhat into the tympanum, forms the round elevation on the inner wall of that cavity called the promontory. The last half-coil is somewhat flattened from above down and its extremity is partly imbedded in the coil next below it.

The *modiolus*, the central pillar or axis of the cochlea, is much the thickest within the first turn of the tube, rapidly diminishing in size in the succeeding parts. Its central part is spongy as far as the last half-coil, and is pierced by many small canals for the passage of the nerves and vessels to the spiral lamina; one of these canals, larger than the rest—*central canal of the modiolus*—runs from the base through the centre of the modiolus (fig. 251). The base of the modiolus appears in the internal auditory meatus as the area cochleæ containing the foramen centrale and the tractus spiralis foraminosus: the latter transmitting the nerve-fibres of one and a-half turns of the cochlear tube, the former being continued into the central canal of the modiolus and transmitting the nerve-fibres for the uppermost turn.

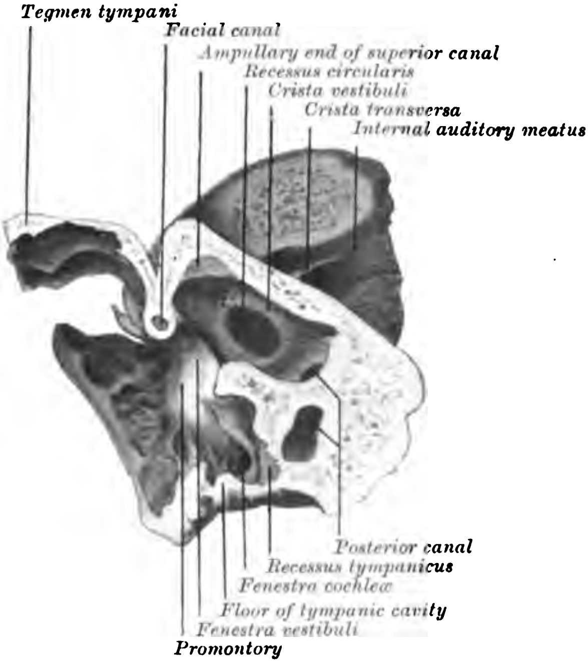
Tegmen tympani
Facial canal
Ampullary end of superior canal
Recessus circularis
Crista vestibuli
Crista transversa
Internal auditory meatus
Posterior canal
Recessus tympanicus
Fenestra cochleæ
Floor of tympanic cavity
Fenestra vestibuli
Promontory

FIG. 249.—THE PETROUS PART OF THE LEFT TEMPORAL BONE OF A NEWLY BORN INFANT. $\frac{3}{1}$. (J. Symington.)

The posterior part of the bone was filed away until the posterior wall of the vestibule and its outer wall as far as the fenestra vestibuli were removed. Internal to the vestibule the internal auditory meatus was opened. The specimen is viewed from behind and from the lateral aspect.

The *osseous spiral lamina* is a thin, flat plate, growing from the modiolus, and projecting into the spiral tube so as to divide it partly into two. It does not reach farther than about half-way towards the outer wall of the spiral tube. Close to the apex of the cochlea it ends in a hook-like process (*hamulus*), which partly bounds the helicotrema. Opposite the lamina spiralis, at the commencement or base of the cochlear tube, is another bony lamina (*secondary spiral lamina*) which nearly meets the spiral lamina, so that there is here only a narrow cleft between the two.

The lamina is dense at its free edge; but nearer the modiolus its internal structure is more open and spongy, and contains numerous small canals for vessels and nerves, continuous with, but running at right-angles to, the canals in the modiolus. Winding round the modiolus, in the base of the spiral lamina, is a small canal named the *spiral canal of the modiolus.*

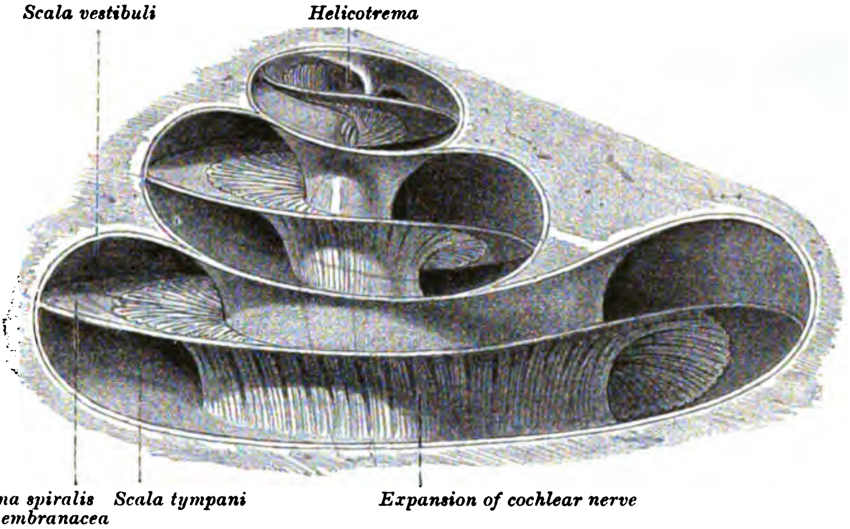
Scala vestibuli
Helicotrema
Lamina spiralis membranacea
Scala tympani
Expansion of cochlear nerve

FIG. 250.—DIAGRAMMATIC VIEW OF THE OSSEOUS COCHLEA LAID OPEN. (Arnold.)

The *scala tympani* (figs. 250, 251), the portion of the tube on the basal side of the lamina spiralis, commences at the fenestra cochleæ, where in the recent state it is separated from the tympanum by the secondary membrane of the tympanum. Close to its commencement is the orifice of a small canal (*aqueductus cochleæ*) which extends downwards and inwards to the lower border of the

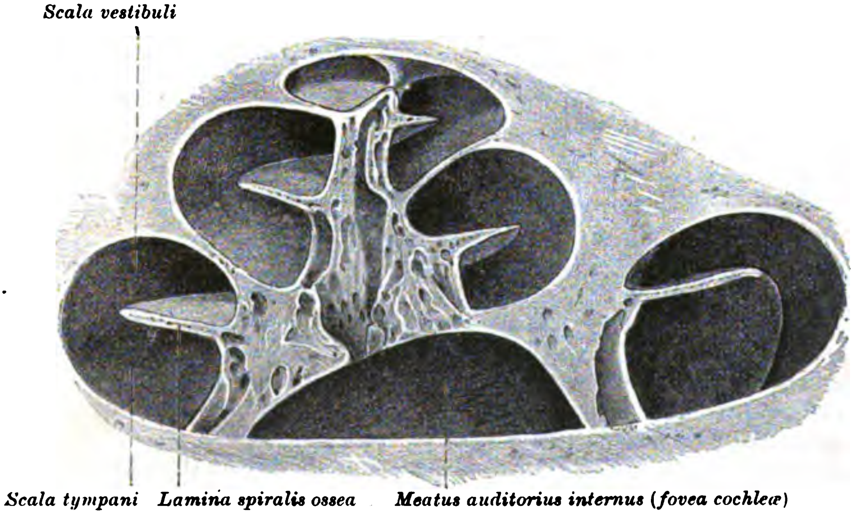
Scala vestibuli
Scala tympani
Lamina spiralis ossea
Meatus auditorius internus (fovea cochleæ)

FIG. 251.—VIEW OF THE OSSEOUS COCHLEA DIVIDED THROUGH THE MIDDLE. (Arnold.)

petrous bone, where it opens into a depression immediately in front of the jugular fossa. It transmits a small vein which joins the inferior petrosal sinus. There is also a communication along the aqueductus cochleæ between the subarachnoid space and the perilymph in the scala tympani. The *scala vestibuli* (figs. 250, 251) is rather narrower than the scala tympani in the first turn of the cochlea, but in the succeeding turns is larger; it commences from the cavity of the vestibule, and communicates, as already described, with the scala tympani at the apex of the modiolus.

THE MEMBRANOUS LABYRINTH.[1]

Within the osseous labyrinth, and separated in most parts from its lining membrane by the perilymph, membranous structures exist in which the ultimate ramifications of the acoustic nerve are spread. In the vestibule and semicircular canals these structures have a general resemblance in form to the complicated cavity in which they are contained. They do not, however, lie loose within the osseous cavity, but along the convex border of the canals, and at the places of entrance of the nerves into the vestibule and ampullæ are fixed to its wall. In the cochlea the membranous structures complete the septum between the scalæ already mentioned, and enclose an intermediate passage—the membranous *canal of the cochlea.* As before stated, the liquid contained within the membranous labyrinth is distinguished as *endolymph.*

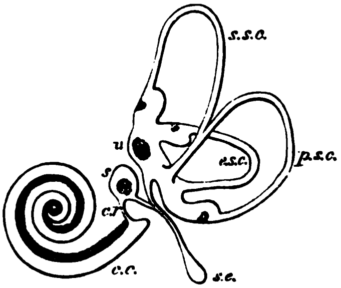

FIG. 252.—PLAN OF THE RIGHT MEMBRANOUS LABYRINTH VIEWED FROM THE MESIAL ASPECT. (E. A. Schäfer.)

u, utricle, with its macula and the three semicircular canals, *s.s.c.*, *p.s.c.*, *e.s.c.*, with their ampullæ; *s*, saccule; *s.e.*, saccus endolymphaticus; *c.r*, canalis reuniens; *c.c.*, canal of the cochlea.

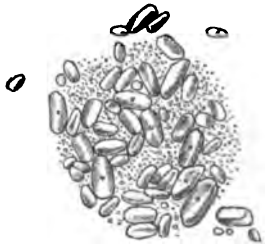

FIG. 253.- OTOLITHS. (From Schwalbe.)

The cavity which contains the perilymph communicates through the sheath of the auditory nerve with both the subdural and subarachnoid spaces.

Within the osseous vestibule are two membranous sacs, the one of which, termed the *utricle,* is connected with the semicircular canals, while the other, the *saccule,* is connected with the cochlea. These two sacs, although in close contact, do not open directly into one another; but they are in indirect communication, in a manner presently to be explained.

The larger of the two sacs, the *common sinus* or **utricle** (figs. 252, *u*; 254, 255, 5), is of a very irregular oblong form, measuring in all 6 mm. to 7 mm. in length, and averaging 5 mm. in breadth, slightly flattened from behind forwards. It is lodged in the upper and back part of the vestibule, occupying the recessus ellipticus and the space immediately below this. The part which lies in the recessus ellipticus is termed the *recessus utriculi* (fig. 256, *R.utr.*). This forms a distinct blind forward projection, some 3 mm. in length, into which, opposite the crista vestibuli, several small branches of the auditory nerve enter from the foramina in the bone; and here the wall of the utricle is thickened, the thickening having a concave surface towards the interior of the utricle, and being covered by auditory epithelium (*macula acustica utriculi*). A small mass of calcareous particles (*otoliths* or *otoconia*) lies within the sac, attached to the macula. These otoliths are crystals of carbonate of lime, rhombic, octahedral, or six-sided, often pointed at their extremities (fig. 253).

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[1] The best description of the membranous labyrinth in man is to be found in the large work of Retzius, 'Das Gehör-organ,' published in 1884. The most complete account of the comparative anatomy is that of Gray, 'The Labyrinth of Animals,' 1907, who gives many exact measurements of its parts in man and animals.

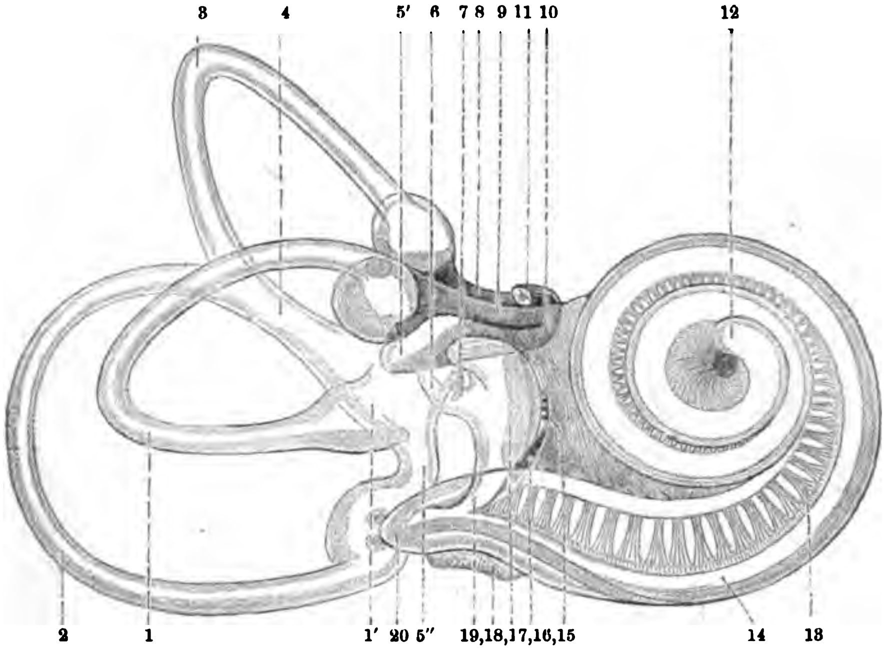

FIG. 254.—RIGHT HUMAN MEMBRANOUS LABYRINTH, REMOVED FROM ITS BONY ENCLOSURE, AND VIEWED FROM THE ANTERO-LATERAL ASPECT. (G. Retzius.)

(The numbers include those of fig. 255.)

1, lateral semicircular canal; 1', its ampulla; 2, posterior canal; 2', its ampulla; 3, superior canal; 3', its ampulla; 4, conjoined limb of superior and posterior canals (sinus utriculi superior); 5, utricle; 5', recessus utriculi; 5'', sinus utriculi posterior; 6, ductus endolymphaticus; 7, canalis utriculo-saccularis; 8, nerve to ampulla of superior canal; 9, nerve to ampulla of lateral canal; 10, nerve to recessus utriculi (in fig. 255 the three branches appear conjoined); 10', ending of nerve in recessus utriculi; 11, facial nerve; 12, lagena cochleæ; 13, nerve of cochlea within spiral lamina; 14, basilar membrane; 15, nerve-fibres to macula of saccule; 16, nerve to ampulla of posterior canal; 17, saccule; 18, secondary membrane of tympanum; 19, canalis reuniens; 20, blind ending of cochlear canal in vestibule: 21, outer wall of cochlea; 22, spiral ligament; 23, section of the seventh and eighth nerves within internal auditory meatus (the separation between them is not apparent).

The ends of all the membranous semicircular canals open into the utricle, and a fine canal (*canalis utriculo-saccularis*) passes from the antero-mesial wall of the utricle, which joins with another one from the saccule to form the *ductus endolymphaticus* (fig. 252).

The ampullæ of the superior and lateral canals open into the roof of the recessus utriculi. The part of the utricle where the ampulla of the posterior semicircular canal opens is termed by G. Retzius *sinus posterior*, and the conjoined limbs of the superior and posterior canals form the *sinus superior* of that author. In all vertebrates below mammals the utricle

has a second macula acustica in its lower part near the sinus posterior (*macula neglecta* of Retzius).

The smaller vesicle, the **saccule** (figs. 252, *s*; 254; 255, 17), is an irregularly oval vesicle about 3 mm. long and nearly 2 mm. broad, and is somewhat flattened from within out. The saccule is situated in the lower and fore part of the cavity of the osseous vestibule, close to the opening from the scala vestibuli of the cochlea, and is received into the hollow of the recessus sphericus, from the bottom of which many branches of nerve enter it, and here there is a similar broad and concave macula in its wall, which is covered by a small mass of otoliths. The upper end of the saccule bends round towards the recessus utriculi, with which it comes in contact, without direct communication (fig. 254).

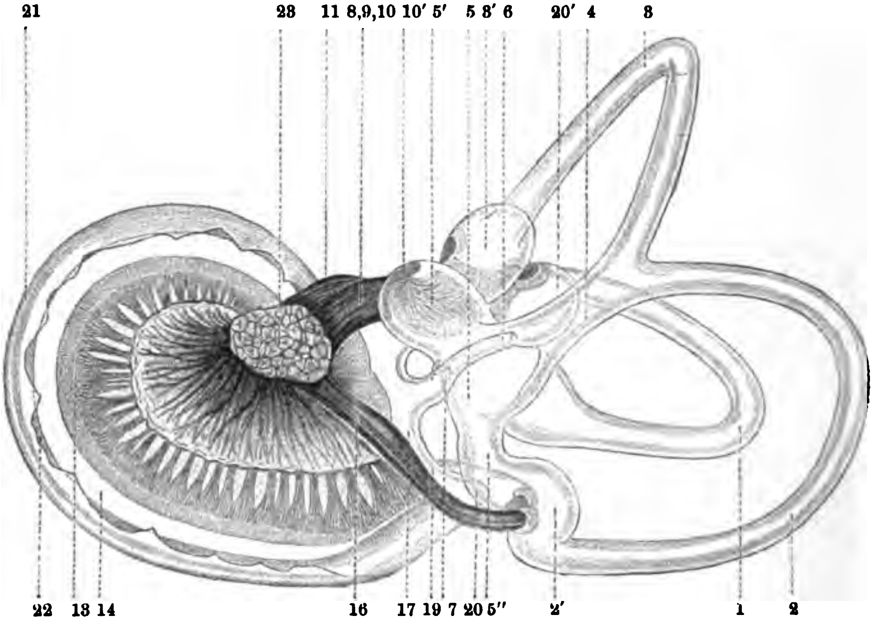

FIG. 255.—THE SAME FROM THE POSTERO-MESIAL ASPECT. $\frac{9}{1}$. (G. Retzius.)

The saccule gradually narrows below into a short funnel-shaped duct (1 mm. long, 0·5 mm. wide), the *ductus reuniens* of Hensen (fig. 252, *c.r.*; figs. 254, 255, 19), which passes downwards and outwards to open directly into the epithelial canal of the cochlea a short distance from its blind lower extremity. There is also, as already mentioned, a canal (*ductus endolymphaticus*, figs. 254, 255, 6), lined with epithelium, which passes from the posterior wall of the saccule along the aqueductus vestibuli to end blindly in a dilated extremity (*saccus endolymphaticus*, fig. 252, *s.e.*) on the posterior surface of the petrous bone just below the orifice of the aqueduct and lying in the tissue of the dura mater (Cotugno). This canal is joined near its origin by a minute tube from the utricle (fig. 254, 7), so that in this way the cavity of the saccule is brought into communication with that of the utricle (Boettcher).

The **membranous semicircular canals** are from one-third to one-fifth the diameter of the osseous tubes in which they are lodged, and are dilated into ampullæ within the ampullary enlargements of those tubes. In section they are oval or somewhat elliptical (fig. 257). The ampullæ measure from 2 mm. to 2·5 mm. in length; they are thicker and less translucent than the rest of the canals, and nearly fill their bony cases, the (membranous) ampullæ being nearly three times the diameter of the canals. That part of each canal which is towards the concavity of the semicircle is free, while the opposite portion is fixed to the wall of the bony canal; in the ampulla this part is flattened and receives branches of nerves and blood-vessels, and on its inner surface is a transverse projection (*septum transversum*) which partly divides the cavity into two, and broadens out somewhat at either end. The most prominent part of the septum, which is surmounted by the auditory epithelium, is termed the *crista acustica*. Seen from above (*i.e.* through the roof of the ampulla), the septum is somewhat fiddle-shaped, the ends being broader than the middle; and beyond each rounded end of the crista is a crescent-shaped edge (covered by columnar epithelium) which has been termed *planum semilunatum* (fig. 256, C.D.).

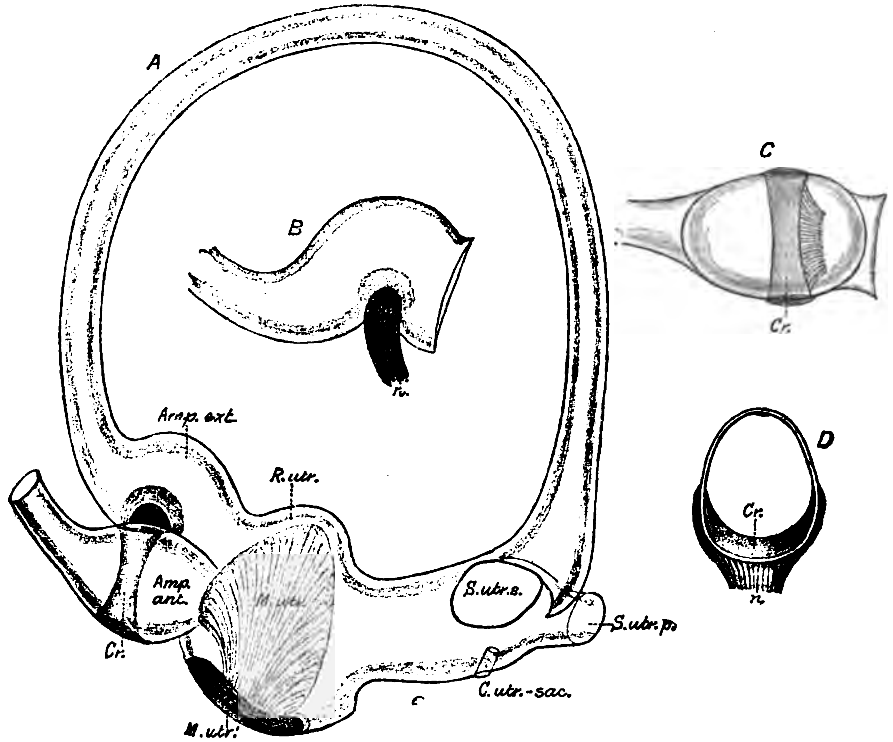

FIG. 256.—VIEWS OF THE LATERAL SEMICIRCULAR CANAL, HUMAN. Magnified. (G. Retzius.)

A, The whole of the lateral canal attached to the utricle, the superior and posterior canals having been cut away. *Amp.ext.*, ampulla of the lateral canal; *Amp.ant.*, ampulla of the superior canal; *Cr.*, crista acustica of the same; *R.utr.*, recessus utriculi; *S.utr.s.*, sinus utriculi superior, cut short; *S.utr.p.*, sinus utriculi posterior, ditto; *C.utr.sac.*, canalis utriculo-saccularis; *M.utr.*, fibres passing to macula recessus utriculi; *M.utr.'*, the same passing round the wall of the utricle.

B, Lateral view of the lateral ampulla; *n*, nerve-bundle entering crista.

C, View of lateral ampulla, showing the free surface of the crista acustica, *Cr.*

D, Transverse sectional view of the lateral ampulla, showing the transverse extent of the crista, *Cr.*; *n*, nerve-fibres.

Branches of the eighth nerve.—Within the internal auditory meatus the eighth nerve divides into two branches, which, broken up into minute filaments, pass through perforations in the plate of bone which separates the meatus from the internal ear, and are distributed respectively to the cochlea and vestibule. In both branches, as well as in the trunk, there are numerous nerve-cells.

The ganglion on the *cochlear branch* (*ganglion spirale, ganglion of the cochlea*) lies within the modiolus at the base of the spiral lamina. The cells of this ganglion are bipolar, and the peripheral processes are distributed in the organ of Corti. The central processes pass down the modiolus and enter the bottom of the internal auditory meatus by a series of small apertures on the tractus foraminosus. They form a rope-like bundle in the meatus, which before reaching the brain becomes joined with the vestibular branch.

The *vestibular branches* are connected with the saccule, the utricle, and the ampullæ of the semicircular canals, and divide into two parts, upper and lower. The *upper division* has a ganglion (*ganglion of Scarpa*) situated in the internal auditory meatus. The peripheral processes of its cells pass into a number of small foramina situated at the outer end of the meatus above the transverse ridge. They enter the vestibule on the crista vestibuli, and are distributed to the utricle and the ampullæ of the superior and lateral semicircular canals. The *lower division* of the vestibular nerve goes to the saccule and the ampulla on the posterior semicircular canal. The saccular portion has a ganglion in the meatus, and the peripheral fibres leave the meatus by a number of minute holes near the commencement of the tractus foraminosus and, entering the vestibule at the spherical recess, pass to the saccule. The ganglion on the fibres of the posterior semicircular canal (ganglion of Corti) is situated near the ampulla in a small canal termed the foramen singulare. All the cells of these several ganglia are bipolar. The nerves of the ampullæ enter the flattened or least prominent side of the ampullæ, where they each form a forked swelling, which corresponds with the crista acustica in the interior of the dilatation.

Vessels of the labyrinth.—The *internal auditory artery*, a branch of the basilar, accompanies the auditory nerve in the internal auditory meatus, and divides into branches for the vestibule and cochlea. Those of the vestibule supply the membranous labyrinth and the endosteum, and small vessels ensheathed by fibrous tissue pass across the cavity containing the perilymph. The blood is chiefly collected into the internal auditory veins which accompany the artery and open into the inferior petrosal sinus, but some is conveyed to the inferior petrosal sinus by fine veins in the aqueductus vestibuli and aqueductus cochleæ. Small arterial branches from the vessels of the dura mater and also from the stylomastoid artery, and from vessels of the middle ear, supply the bony walls of the labyrinth, but do not appear to anastomose with the arteries of the membranous labyrinth.

Structure of the utricle, saccule, and semicircular canals.—Three layers can be distinguished in the membranous walls of the semicircular canals —an outer fibrous stratum, an inner epithelial lining, and between the two a tunica propria. These layers are not of equal thickness throughout, for along the side which is in contact with and supported by the bone (fig. 257) they are thinner than at the rest of the circumference, where they lie free and are bathed by the perilymph. The difference in thickness affects the fibrous layer and the tunica propria only, for the epithelium forms throughout a lining of simple flattened cells.

The *fibrous layer*, which contains some irregular pigment-cells, is composed of ordinary fibrous tissue, similar to that of the periosteum, with which it becomes continuous at the parts where the two structures are in contact.

It is especially developed at the ends of the oval section, whence well-marked bands of fibrous tissue pass to the periosteum (fig. 257, *c.t.*). More delicate bands of fibrous tissue traverse the perilymph to become connected with the periosteum of the opposite wall of the canal. Both along these bands, and also more directly from the contiguous periosteum, numerous small blood-vessels pass into the fibrous layer and there break up into a coarse capillary network, the branches of which do not, in man, pass into the tunica propria.

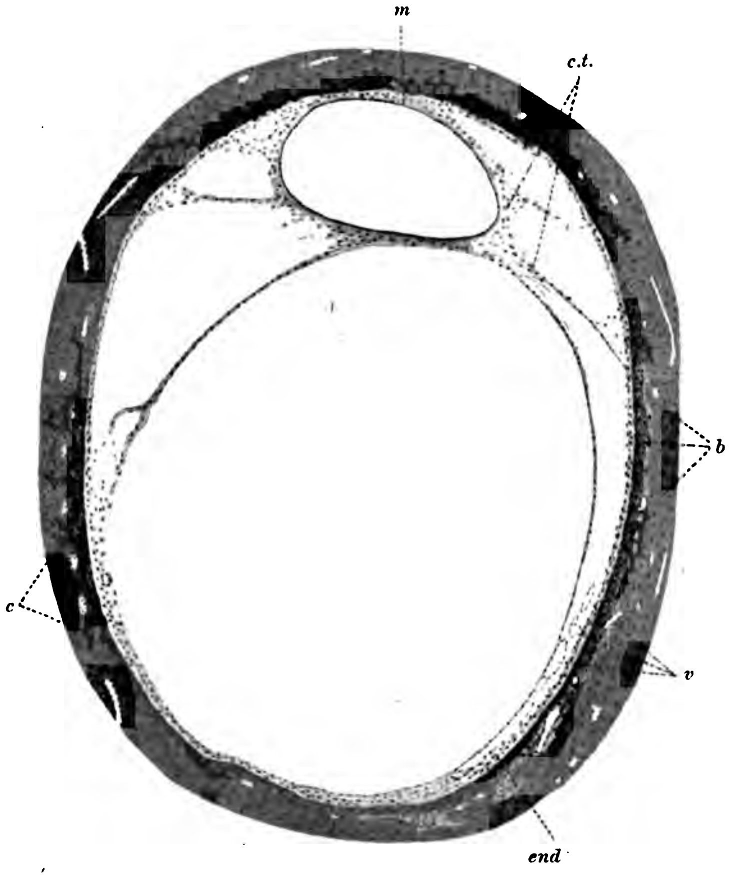

FIG. 257.—SECTION OF A SEMICIRCULAR CANAL, NEW-BORN CHILD. Magnified 55 diameters. (Sobotta.)

c.t., connective-tissue strands, between membranous canal and endosteum of bony canal; *m*, membranous canal; *b*, bony canal; *c*, remains of fœtal cartilage; *end*, endosteum; *v*, blood-vessels.

The *tunica propria* is a clear membranous structure continuous around the whole tube, although thinning off very much opposite the part where the membranous canal is in contact with the bone. Externally it is not very distinctly marked off from the fibrous coat; internally it may show a number of papilliform eminences which project into the interior of the canal except at the thinnest part (Rüdinger).

The *epithelial lining* takes the form of a complete layer of flattened cells, which in the human semicircular canals are of the same nature throughout, except along the outer part of the semicircle, where there is a longitudinal tract of cells which are more elongated than the rest. This line is sometimes termed the raphe of the canal.

In many of the lower animals—birds and fishes—some of these lining cells are columnar, while in one species of fish (*Salmo hucho*), as described by Rüdinger, a tract along the whole length of each canal becomes developed into two rows of rounded cells, from each of which a long filament extends to the wall of the canal in a direction transverse to the axis.

The **ampullæ**, as well as the saccule and utricle, agree generally in structure with the semicircular canals; but are everywhere united by a layer of delicate connective tissue with the wall of the bony canal. This tissue forms a marked thickening opposite the entrance of the nerve-fibres and projects into the cavity as the *septum transversum* surmounted by the *crista acustica*, before mentioned (fig. 259). Through the substance of this thickening the nerve-fibres pass to the edge of the ridge, and over it the epithelium is of an elongated columnar form, and is surmounted by long, conical, gradually tapering filaments (auditory hairs, fig. 258, *h*), which project stiffly into the cavity, and are about 0·03 mm. in length. These hairs are borne by pear-shaped epithelium-cells (fig. 259), a single hair projecting from each cell; but under the influence of reagents they are apt to become broken near the base, and split up into fine fibrils which appear as a bunch of cilium-like filaments attached to the free border of the cell. The pear-shaped cells, or *hair-cells*, do not extend down to the basement-

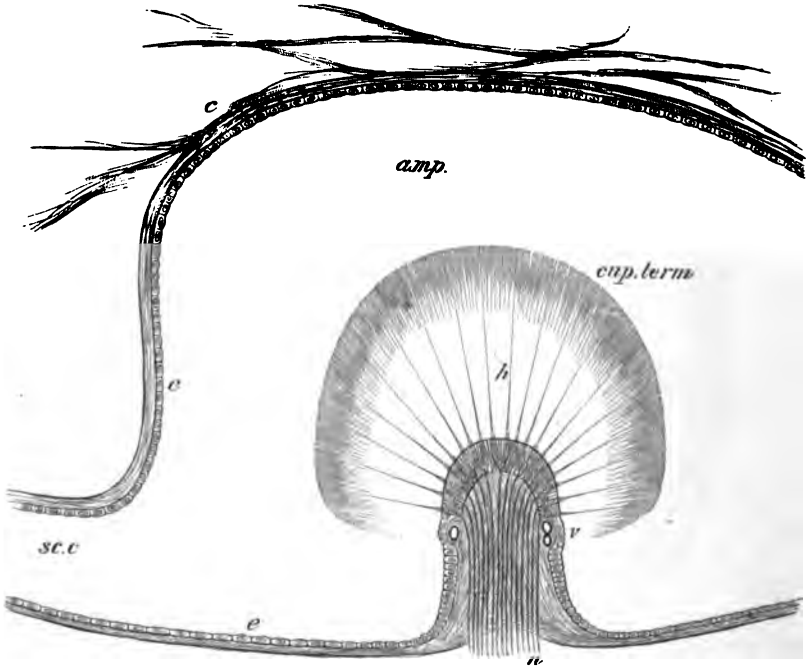

FIG. 258.—LONGITUDINAL SECTION OF AMPULLA OF A FISH, TAKEN THROUGH THE CRISTA ACUSTICA. Diagrammatic. (E. A. Schäfer.)

amp., cavity of the ampulla; *sc.c*, semicircular canal opening out of it; *c*, connective tissue attached to the wall of the membranous ampulla and traversing the perilymph; *e e*, flattened epithelium of ampulla; *h*, auditory hairs projecting from the columnar cells of the auditory epithelium into the cupula, *cup.term*; *v*, limit of the auditory epithelium on the crista; *n*, nerve-fibres entering the base of the crista and passing into the columnar cells.

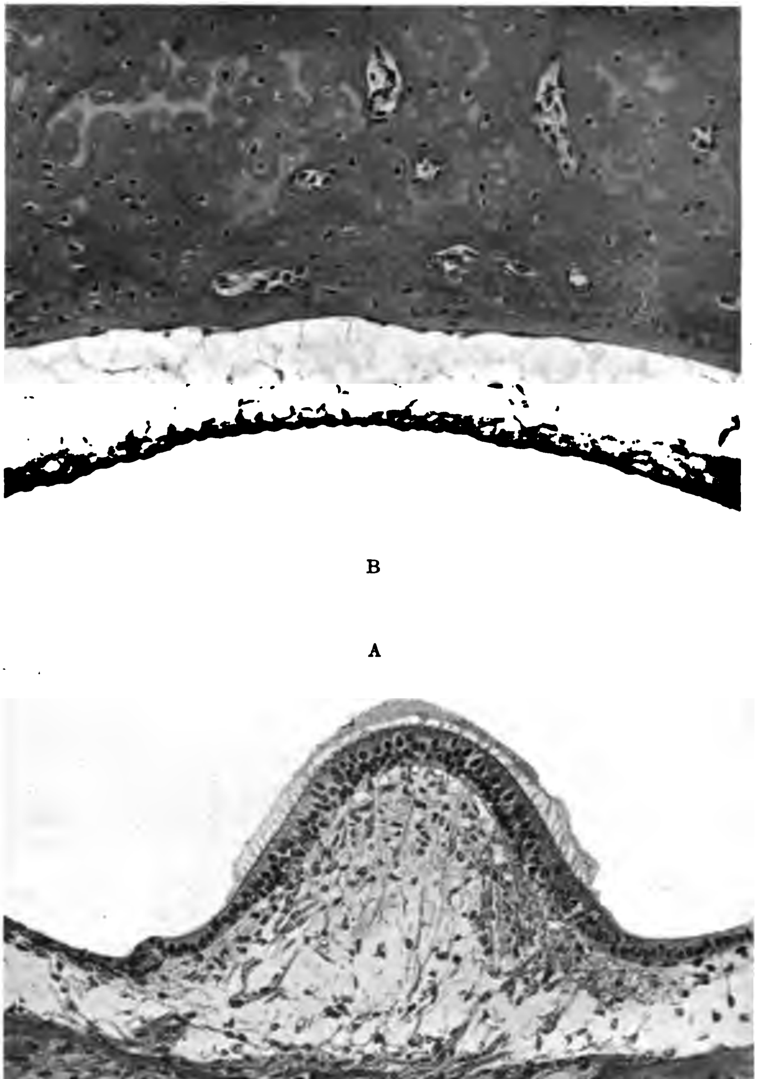

FIG. 259. — FROM A LONGITUDINAL SECTION OF AN AMPULLA OF A GUINEA-PIG, SHOWING IN THE LOWER PART (A) THE CRISTA ACUSTICA, COVERED WITH HAIR-CELLS, THE HAIRS PROJECTING INTO THE REMAINS OF THE CUPULA; AND IN THE UPPER PART (B) THE FLATTENED EPITHELIUM OF THE OPPOSITE WALL, SEPARATED BY DELICATE CONNECTIVE TISSUE FROM THE BONY WALL. (Photographed from a preparation by H. Pringle.)

In the lower part the bundles of nerve-fibres may be seen passing from canals in the bony wall into the crista, and extending to its epithelium. The hair-cells, the protoplasm of which is less stained than that of the other epithelium-cells, are pear-shaped, the hair projecting from each like the stalk of the pear. At the edge of the crista the epithelium is observed to become columnar and eventually (left side) flattened. On this side pigmented cells occur immediately below the epithelium.

membrane, but terminate short of this in a rounded extremity. They are surrounded by the branching axis-cylinders of the nerve-fibres which penetrate into the epithelium; the medullary sheath disappears as the fibres enter the epithelial layer, and the axis-cylinders ramify amongst the cells, but there does not appear to be any actual continuity between the terminal arborisations of the nerve-fibres (fig. 263) and the hair-cells.

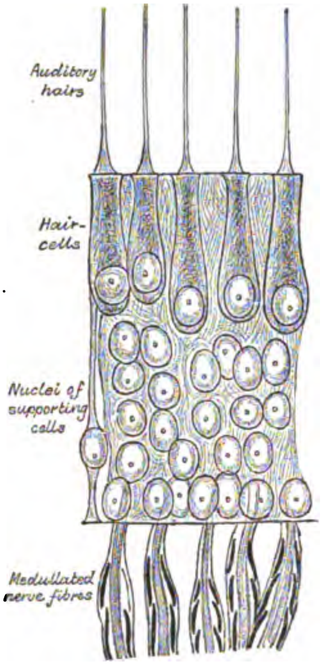

FIG. 260.—SECTION OF EPITHELIUM OF AMPULLA OF LACERTA VIRIDIS. Magnified. (G. Retzius.)

Between and beneath the columnar cells, other cells are met with of a different character (fig. 260). They take the form of long and comparatively rigid fibres (*fibre-cells* of Retzius) which extend through the whole thickness of the epithelium, and are provided at one part of their course with a nucleated enlargement. This is always placed below the columnar cells, and in many it is close to the central end of the fibre. The fibres, which are probably sustentacular in function, like the fibres of Müller in the retina and the cells of Deiters in the cochlea, expand slightly as they approach the free surface, and appear to become attached to a cuticular structure which encloses the ends of the hair-cells and is thus comparable to the reticular lamina of the cochlea (Urban Pritchard). On the other hand, the fibres are set by their central ends upon a limiting membrane which bounds the epithelium next to the tunica propria, and which appears in section as a fine but well-marked line.

The limit of the auditory epithelium at the sides of the crest is sometimes marked, at least in the human ampullæ, by a slight projection, caused by a prominent subjacent blood-vessel. This is visible in fig. 259.

The auditory hairs were first noticed by Max Schultze, who described them as being connected with the elongated cells, now known to be sustentacular. Their true relations were pointed out by Retzius. When the cells are isolated after preservation in osmic acid, the separated pear-shaped cells are alone surmounted by auditory hairs, whereas the elongated intermediate cells are not provided with auditory filaments. It is worthy of note that the auditory hairs do not, in sections made from hardened specimens, appear to project freely into the endolymph of the ampulla, but into a soft material which takes a dome-like shape (*cupula terminalis*, Lang), and appears to possess an indistinctly fibrillar structure.

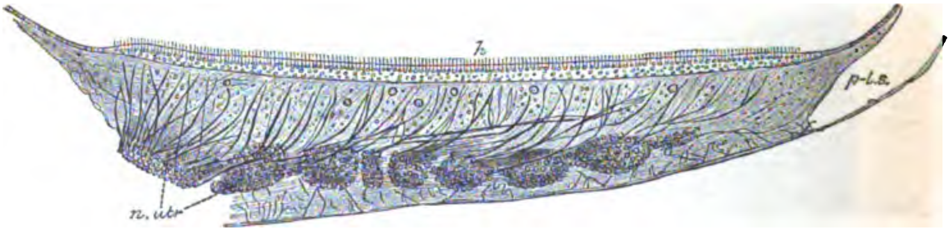

FIG. 261.—SECTION OF THE MACULA ACUSTICA OF THE RECESSUS UTRICULI, HUMAN. Magnified. (G. Retzius.)

n.utr, bundles of the utricular branch of the eighth nerve; *h*, hair-cells; *p.l.s.*, perilymphatic space.

The foregoing description of the characters of the epithelium and mode of nerve-distribution in the cristæ acusticæ of the ampullæ is equally applicable to the maculæ acusticæ of the saccule and utricle. But the nerves which are supplied to the maculæ spread out more than those to the ampullæ. The auditory hairs are shorter than those of the ampullæ. As before mentioned, both saccule and utricle contain in their cavity and lying in contact with the nerve-epithelium a little mass of otoliths, which, however, do not float free in the fluid, but appear imbedded in a soft matrix. Otoliths may also be found scattered here and there in the ampullæ and semicircular canals.

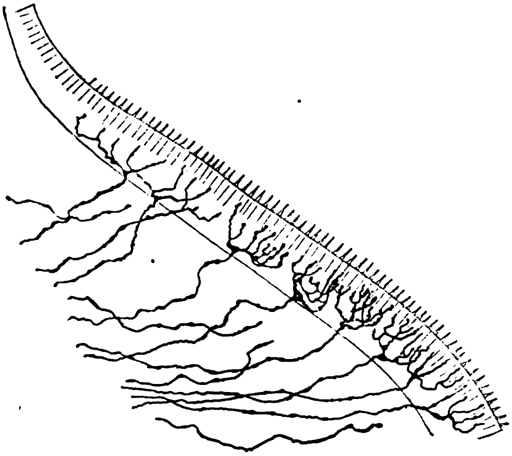

FIG. 262.—NERVE TERMINATIONS IN MACULA ACUSTICA. Shown by Golgi's method. (G. Retzius.)

The **membranous cochlea**, which occupies the spirally wound tube of the osseous cochlea, consists like this of about two and three-quarter turns, which may be termed respectively the *basal*, *middle*, and *apical*, the last-named being incomplete. The total length of the tube is about 35 mm. In structure it resembles the membranous semicircular canals just described in consisting of a tube, lined by epithelium and containing endolymph, partly surrounded by a clear space containing perilymph; but it differs from them both in shape and in the modifications presented by its epithelial lining. In macerated specimens, the two parts into which the osseous tube of the cochlea is divided are, it will be remembered, only imperfectly separated by the osseous spiral lamina which projects from the columella; but in the fresh specimen the tube is separated completely into three distinct parts by means of two membranes, which extend along its whole length (figs. 264 to 267). In the first place, the lamina spiralis is directly prolonged by a comparatively strong, well-marked membrane, the *basilar membrane*, which stretches straight across to the outer wall of the

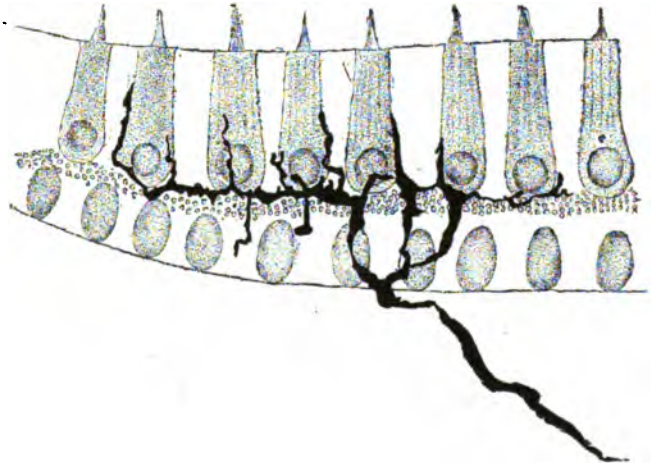

FIG. 263.—A NERVE-FIBRE TERMINATING AMONGST THE PEAR-SHAPED HAIR-CELLS OF MACULA. Golgi method. (L. Barker, after Lenhossék.)

The lower nuclei belong to sustentacular cells.

cochlea, and is here connected to an inward projection of the lining periosteum and sub-periosteal tissue known as the *spiral ligament*. The basilar membrane thus helps to complete the upper[1] limit of the scala tympani, but does not, properly speaking, enter into the lower boundary of the scala vestibuli, for a second, much more delicate membrane, known as the membrane of Reissner, passes from the upper part of the lamina a little distance from its end, and stretches obliquely upwards and outwards, also to become connected with the lining periosteum. The oblique direction of the membrane of Reissner causes a triangular space to be shut off between it and the basilar membrane, which is bounded externally by the outer osseous wall of the cochlea lined by periosteum; and this space, extending throughout the whole length of the osseous tube, and lined throughout by an epithelium variously modified in different parts, is known distinctively as *the canal of the cochlea, canalis membranaceus*, or *ductus cochlearis* (fig. 264, *cc*; figs. 265, 266, 267). It terminates in a blind extremity at the apex (*lagena*, fig. 268),[2] and another at the base. That at the apex, extending beyond the hamulus, is fixed to the wall of the cupola, and partly bounds the helicotrema; that at the base fits into the angle at the commencement of the osseous spiral lamina in front of the floor of the vestibule. Near to this blind extremity the canal of the cochlea receives a small canal, lined with epithelium—*canalis reuniens* (Hensen)—which is continued from the saccule of the vestibule like the neck of a flask, and enters the canal of the cochlea abruptly nearly at a right-angle (figs. 252, 254). The cavity of the canal of the cochlea is thus rendered continuous with that of the saccule.

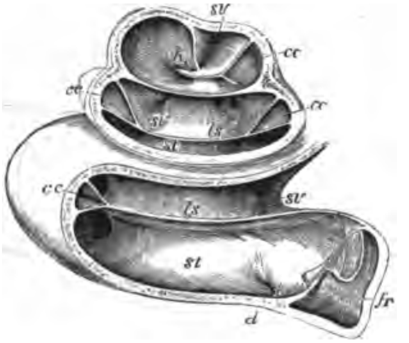

FIG. 264.—LEFT COCHLEA OF A CHILD SOME WEEKS OLD. $\frac{6}{1}$. (Reichert.)

The drawing was taken from a specimen which had been preserved in alcohol, and was afterwards dried; a section is made so as to show the lamina spiralis, scalæ, and cochlear canal in each of the three coils: the membranous spiral lamina is preserved, but the appearances connected with the organ of Corti, etc., have been lost from drying. *fr*, fossula of the fenestra rotunda. The secondary membrane of the tympanum is seen at the bottom of the fossula attached below to a bony projection of the lower wall (crista semilunaris, to the right of *d*); *st*, scala tympani; *sv*, scala vestibuli. In the lowermost turn the scala tympani is seen to be the larger: in the higher turns the proportions are reversed; *ls*, lamina spiralis; *h*, hamulus; *cc*, canalis cochleæ; *d*, opening of the aqueductus cochleæ.

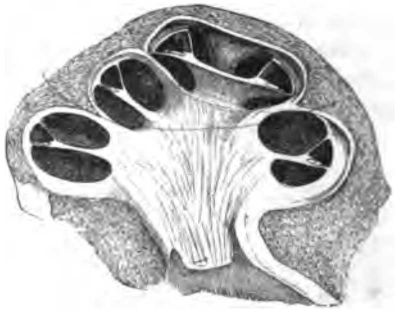

FIG. 265.—VERTICAL SECTION OF THE COCHLEA OF A FŒTAL CALF. $\frac{6}{1}$. (Kölliker.)

In this specimen the external wall was ossified, but the modiolus and spiral lamina were still cartilaginous: the section shows in each part of the cochlear tube the two scalæ with the intermediate canalis cochleæ and lamina spiralis.

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[1] To avoid repetition, it may here be stated that for convenience sake the cochlea is considered in the present description as having its larger part or base lowermost, and the domed extremity uppermost, although of course this is far from being the relative position of the parts whilst within the body. Moreover, parts nearer the columella are spoken of as *inner*; parts nearer the external wall as *outer*.

[2] In monotremes and in birds, reptiles, amphibia, and fishes, there is a specially modified patch of auditory epithelium at the lagena, similar to the maculæ of utricle and saccule, and provided with otoliths. In fishes this is the only nerve-terminal apparatus in the cochlea, which is also otherwise quite rudimentary.

The structures which are found upon the *floor* of this spirally wound triangular canal of the cochlea claim more particular attention, for it is to them that the branches of the cochlear nerve are distributed, and upon them the function of the cochlea as a part of the auditory apparatus appears more especially dependent.

The floor itself of the cochlear canal is formed of a narrow portion of the spiral lamina external to the membrane of Reissner, and of the basilar membrane. In the macerated specimen this part of the lamina thins off gradually to a fine edge like the blade of a knife, but in the recent condition it retains its thickness for some distance (or even exhibits a slight increase), and then abruptly terminates with a border which in section is C-shaped, with the lower limb of the C (*labium tympanicum*) much more prolonged and tapering than the upper (*labium vestibulare*). The lower limb is in fact the section of the end of the osseous lamina, together with a thin membranous layer which covers it, and which is directly prolonged into the basilar membrane. This membrane, as well as the whole thickened upper part of the edge of the spiral lamina, not being ossified, disappears in the process of maceration. The thickened part (fig. 269, *l*), with its somewhat overhanging, crest-like edge, is known as the *limbus* of the spiral lamina, and the groove which it overhangs, and which in section is represented by the bay of the C, is known as the *spiral groove* (fig. 269, *s.sp.*).

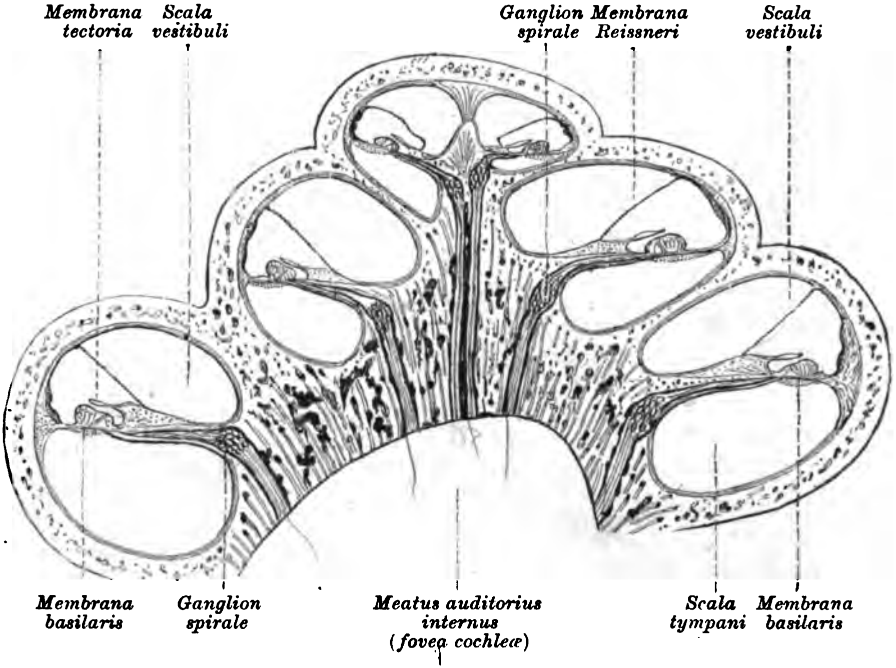

FIG. 266.—SECTION THROUGH THE MIDDLE OF THE COCHLEA. Diagrammatic. (E. A. Schäfer.)

The tissue of which the **limbus** is composed seems to be a peculiar form of connective tissue. Towards the under and inner part there are numerous corpuscles and the texture is fibrous, but above and near the crest few or no connective-tissue corpuscles are met with, and the tissue has a columnar aspect with somewhat regularly arranged nuclei. The fibrillated tissue is prolonged,

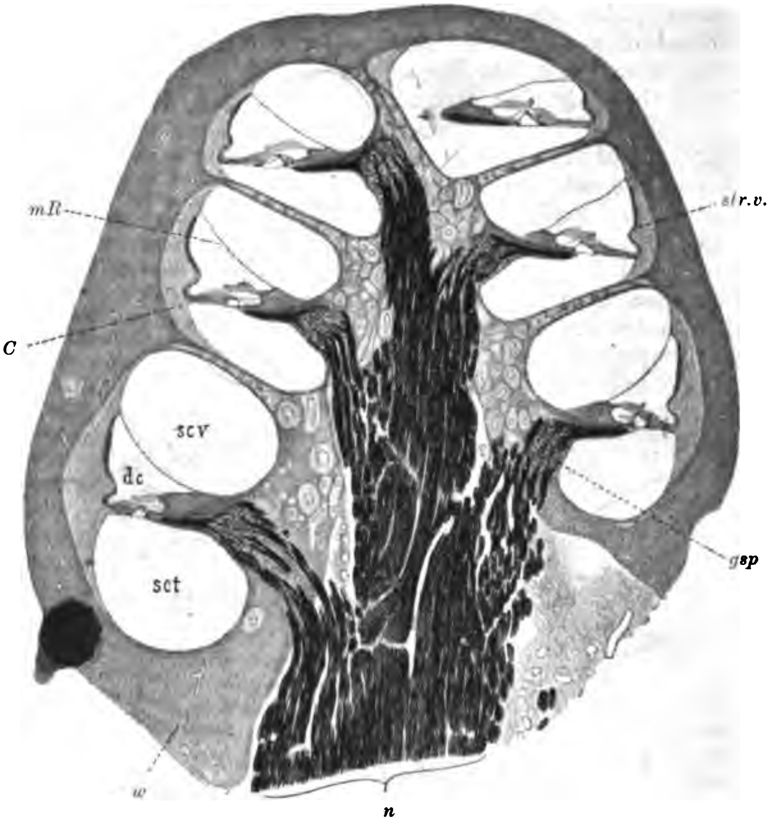

FIG. 267.—SECTION THROUGH THE COCHLEA OF THE CAT. Magnified 25 diameters. (Sobotta.) *dc*, duct of cochlea; *scv*, scala vestibuli; *sct*, scala tympani; *w*, bony wall of cochlea; *C*, organ of Corti on basilar membrane; *mR*, membrane of Reissner; *n*, nerve-bundles in modiolus; *gsp*, ganglion spirale; *str.v.*, stria vascularis.

as just intimated, beyond the osseous lamina, into the basilar membrane. Near its termination, close to the junction with the basilar membrane, it is perforated with a number of regularly arranged, elongated apertures (fig. 270, *p*), about 4,000 in number, which serve for the transmission of bundles of the nerve-fibres. The latter, in their course from the spiral ganglion to the auditory epithelium, are lodged, as far as this, in canals in the lower osseous part of the spiral lamina (figs. 267, 274). Their arrangement will be afterwards more fully described.

When the limbus is viewed from above, the vestibular edge is seen to present a succession of tooth-like

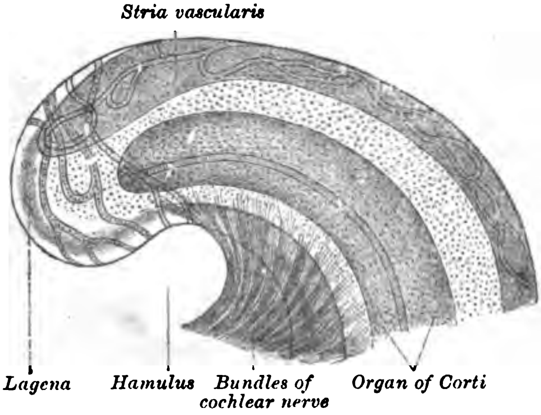

FIG. 268.—APEX OF COCHLEAR CANAL. (Retzius.)

projections (fig. 270, *Cr*), about 7,000 in number altogether, which give it a jagged aspect. These projections are continued as flattened eminences a short distance on the upper surface of the limbus, which is therefore not smooth, at least near the edge, but marked in this way with eminences and intervening furrows. Nearer the line of origin of the membrane of Reissner it becomes smoother, and here, too, its epithelial covering, which is directly continuous with that of the under surface of Reissner's membrane, is evenly distributed; whereas at the crest itself the epithelial cells are columnar in the furrows, but flattened out over the teeth, so as to be invisible here with ordinary methods of preparation. Their outlines can, however, according to G. Retzius, be brought to view by the employment of the silver method. Immediately below the overhanging projections, the epithelium again forms a well-defined layer of cubical or short columnar cells which lines the spiral groove, and is continuous externally with the specialised cells, presently to be described as forming the organ of Corti.

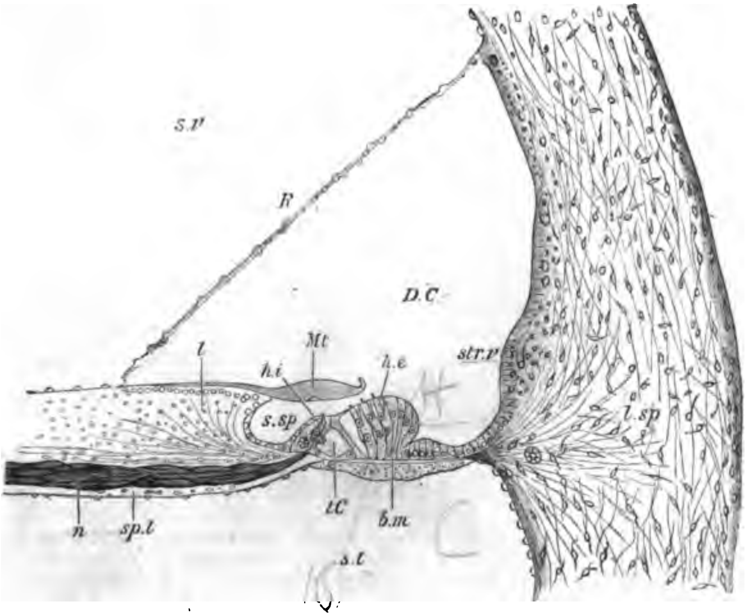

FIG. 269.—SECTION ACROSS THE BASAL TURN OF THE HUMAN COCHLEA. Magnified. (G. Retzius.)

D.C, ductus cochleæ; *s.v*, scala vestibuli; *s.t*, scala tympani; *R*, membrana Reissneri; *Mt*, membrana tectoria; *b.m*, membrana basilaris; *str.v*, stria vascularis; *l.sp*, ligamentum spirale; *l*, limbus; *s.sp*, sulcus spiralis; *t.C*, tunnel of Corti; *h.i*, inner hair-cells; *h.e*, outer hair-cells; *n*, nerve-fibres; *sp.l*, spiral lamina.

The **basilar membrane** stretches, as before mentioned, straight between the osseous lamina and the spiral ligament, and separates the canal of the cochlea from the scala tympani. It increases in breadth, at first rapidly but afterwards more gradually, from the base to the apex of the cochlea, while the breadth of the osseous spiral lamina diminishes. Hensen states that at the lowest part of the cochlea, where this membrane occupies the narrow cleft between the lamina spiralis ossea and the lamina secundaria, the breadth is only about 0·041 mm.; but towards the apex of the cochlea it increases at the expense of the bony lamina, until, near the helicotrema, the membranous part is left almost unsupported by any plate of bone, measuring as much as 0·495 mm., or about twelve times as much as at the base. The average measurements given by Retzius are, on the other hand, for the first or basal turn 0·21 mm.; for the middle turn 0·34 mm.; and for the apical turn 0·36 mm. Its total length averages, according to Retzius, 33·5 mm. The basilar membrane is usually described as showing two zones—viz. the *zona arcuata*, which is the part upon which the rods of Corti stand, and the *zona pectinata*, extending from the feet of the outer rods to the spiral ligament, the latter zone being somewhat thicker and much more distinctly fibrous. The proper substance of the membrane appears to be formed of a homogeneous ground-substance containing nuclei imbedded in it here and there, and having straight fibres (running radially from the spiral lamina to the external spiral ligament) imbedded in it, so that the membrane, especially its outer part, presents a marked striation when viewed on the surface (fig. 271). Externally, at its attachment to the spiral ligament, it breaks up into diverging fibres, which spread into that projection.

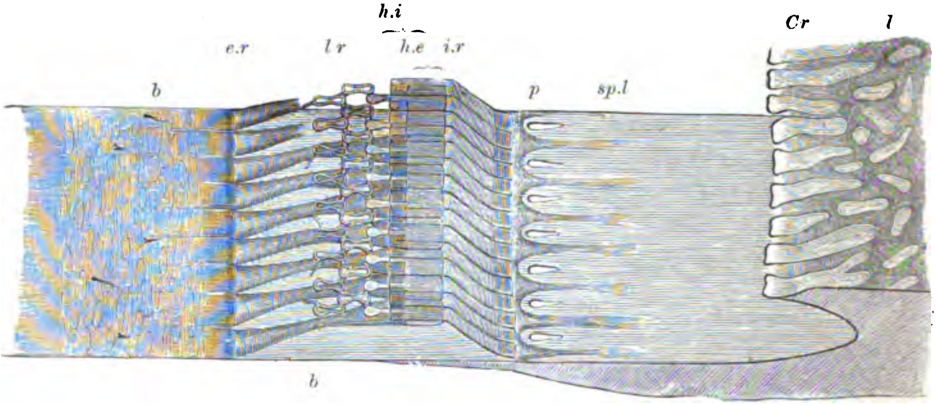

FIG. 270.—SEMI-DIAGRAMMATIC VIEW OF PART OF THE BASILAR MEMBRANE AND TUNNEL OF CORTI OF THE RABBIT, FROM ABOVE AND THE SIDE. Much magnified. (E. A. Schäfer.)

l, limbus; *Cr*, labium vestibulare or crest of limbus with tooth-like projections; *b*, *b*, basilar membrane; *sp.l*, spiral lamina with, *p*, perforations for transmission of nerve-fibres; *i.r*, fifteen of the inner rods of Corti; *h.i*, their flattened heads seen from above; *e.r*, nine outer rods of Corti; *h.e*, their heads, with the phalangeal processes extending outward from them and forming, with the two rows of phalanges, the lamina reticularis, *l.r*. On the left of the figure the connective-tissue fibres and nuclei of the undermost layer of the basilar membrane are seen through the upper layers. Portions of the basilar processes of the cells of Deiters remain attached here and there to the membrane at this part.

In a section of the membrane across the direction of its fibres the latter appear as fine points enclosed by the homogeneous ground-substance (fig. 272). In chemical nature they resemble elastic fibres, but are rather less resistant to alkalies and most other reagents. It has been calculated by Retzius that there are altogether as many as 24,000 of these fibres in the human membrana basilaris, but they do not all run singly, some being grouped together. On the upper surface of the membrane is the epithelium which forms the organ of Corti, continued laterally by a single layer of cells (fig. 273): a delicate cuticular layer which is seen in section is perhaps formed by this epithelium. On the under surface the membrane is covered by a layer of connective tissue (often described as part of the membrane), the fibres of which have a direction parallel with the spiral, and across that of the fibres of the membrane proper. There are numerous intermixed spindle-shaped corpuscles in this tissue, which is in continuity with the lining periosteum of the scala tympani. Small blood-vessels are found in it, but as a rule extending only over the inner part of the membrane. They are usually terminated by a rather larger longitudinally running vessel, situated opposite the outer rods of Corti, and known as the *vas spirale* (fig. 274).

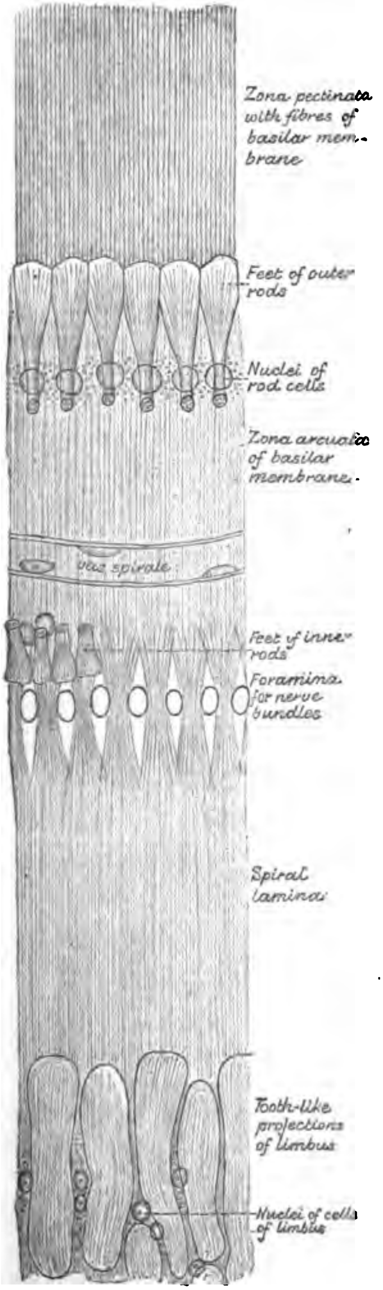
Zona pectinata with fibres of basilar membrane
Feet of outer rods
Nuclei of rod cells
Zona arcuata of basilar membrane
vas spirale
Feet of inner rods
Foramina for nerve bundles
Spiral lamina
Tooth-like projections of limbus
Nuclei of cells of limbus

FIG. 271. — BASILAR MEMBRANE AND LIMBUS VIEWED FROM ABOVE. Magnified. (G. Retzius.)

The **membrane of Reissner** (fig. 269, *R*) separates the scala vestibuli from the canal of the cochlea. It is composed of an exceedingly delicate layer of connective tissue continuous with the lining periosteum of the scala vestibuli, and is covered on the surface which is turned to the cochlear canal with a simple pavement-epithelium. This is in continuity below with the epithelium of the limbus and above with that lining the outer wall of the canal. The cells have each a circular flattened nucleus, and not unfrequently contain fat-droplets. The vestibular side of the membrane of Reissner is quite smooth, and is covered with an epithelioid layer of flattened connective-tissue cells, distinguishable from the epithelial cells on the other side by their greater delicacy of outline and their larger size. A few blood-capillaries are continued into the adjacent part of the membrane from the neighbouring periosteum.

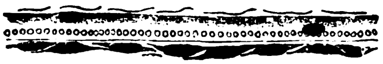

FIG. 272.—TANGENTIAL SECTION ACROSS THE ZONA PECTINATA OF THE BASILAR MEMBRANE OF THE GUINEA-PIG. Highly magnified. (Schwalbe.)

Outer wall of the cochlear canal.—The periosteum which lines the scala vestibuli and scala tympani consists of ordinary connective tissue. There is no continuous lining of flattened cells on the free surface, such as covers the surface of serous membranes. On the other hand, the periosteum which bounds the canal of the cochlea externally is much thickened by a development of reticular connective tissue, and is covered by the epithelium of that tube, which here forms a single layer of columnar cells, which contain pigment, and are prolonged by forked or arborescent processes into the subjacent connective tissue. There is usually a slight inward projection a little above the spiral ligament, containing a prominent blood-vessel (figs. 269, 273). In the tract between this prominence and the membrane of Reissner the substance of the periosteum is also frequently pigmented, and from containing large and numerous blood-vessels, the capillary loops of which project between the epithelium-cells, is termed *stria vascularis*. Immediately beneath this epithelium of the outer wall is a basement-membrane, through which, in section, the cell-processes above mentioned may be seen passing from the epithelium into the subjacent connective tissue.[1]

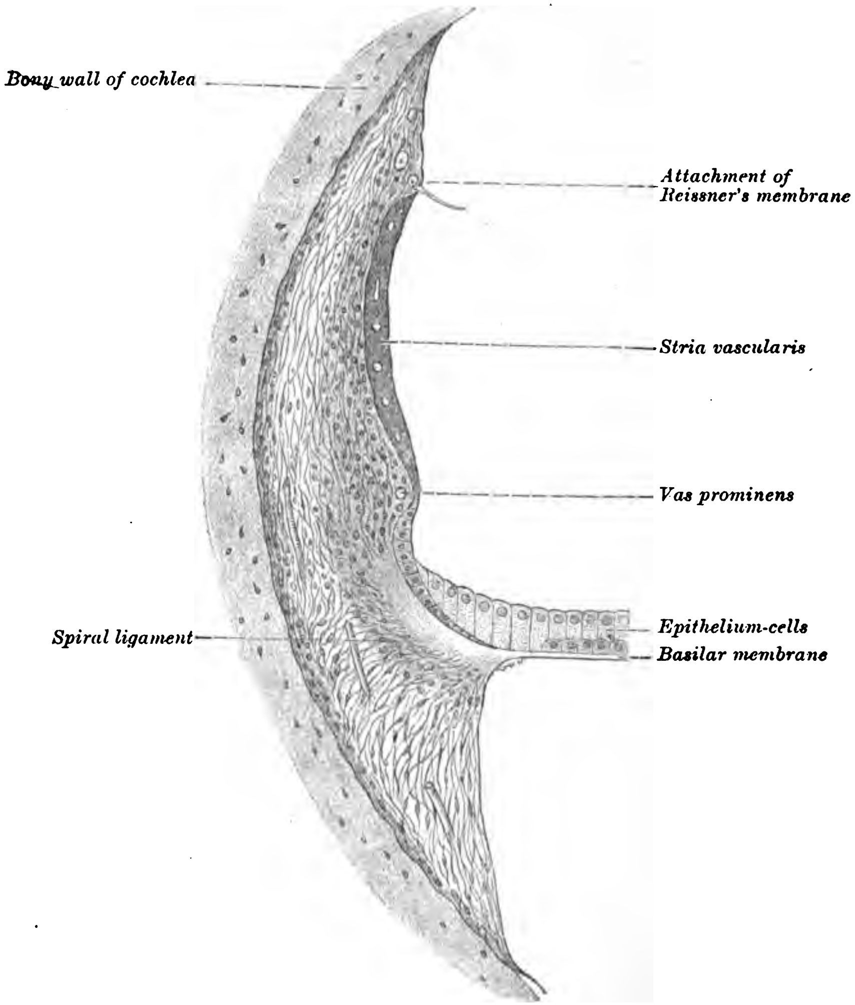
Bony wall of cochlea
Attachment of Reissner's membrane
Stria vascularis
Vas prominens
Epithelium-cells
Basilar membrane
Spiral ligament

FIG. 278.—SECTION SHOWING THE STRUCTURE OF THE LIGAMENTUM SPIRALE AND ADJACENT PARTS, FROM THE GUINEA-PIG'S COCHLEA. $\frac{130}{1}$. (Schwalbe.)

The **spiral ligament** (fig. 269, *l.sp.*; fig. 273) appears in section as a triangular prominence attached to the outer wall of the cochlea, with the basilar membrane prolonged from its apex. It is composed of a retiform connective tissue, many of the cells of which have an elongated shape and radiate from the point of attachment of the basilar membrane. They have been considered by some to be muscular, but there is no distinct proof of their contractile nature.

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[1] On the epithelium of the sulcus spiralis externus, see Retzius, *op. cit.*, and in Biol. Unters. ix. 1900; Stöhr, Verh. d. Anat. Gesel., Anat. Anz. 1907; and A. Hann, *ibid.*

Organ of Corti.—The epithelium which covers the basilar membrane includes the highly specialised structures which are known by the name of the **organ of Corti** (fig. 274). The central part of this apparatus is formed by two sets of stiff rod-like bodies—the inner and outer *rods of Corti* (fig. 275)—which stand upon the basilar membrane, the outer series (*e.r.*), at some little distance from the inner (*i.r.*), and are inclined towards each other, coming in contact above. In this way each pair of rods forms a pointed arch with slanting sides, and since the rods of each series are in lateral juxtaposition the double row of inclined columns forms a tunnel (fig. 270) along the whole extent of the cochlear canal.

On the inner side of the inner series of rods is a row of epithelial cells (fig. 274), which are surmounted by a brush of fine, short, stiff hairlets, and external to the outer rods are three or four successive rows of similar but more elongated cells. These cells are termed respectively the *inner* and *outer hair-cells*. The hairlets of the outer hair-cells project through apertures in a curiously formed cuticular membrane, termed the *reticular lamina* (fig. 270, *l.r.*; fig. 278), which covers this part of the organ of Corti like a wire net. The hairlets of the inner hair-cells are one and a-half times as long as those on the outer hair-cells (Retzius). The hairlets in man may be seen to converge as they are traced downwards into the cell-protoplasm, the group which they form being shaped like a shoe-horn.[1]

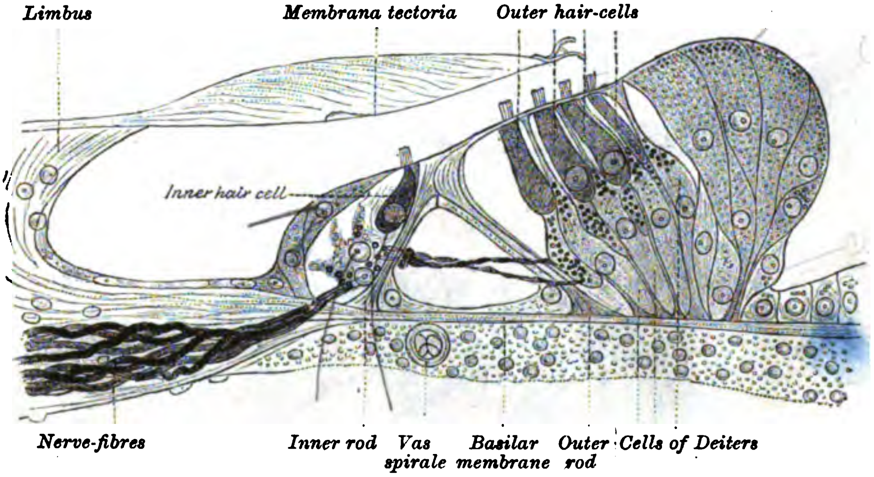

FIG. 274.—SECTION THROUGH THE ORGAN OF CORTI OF THE MIDDLE TURN OF THE HUMAN COCHLEA. Highly magnified. (G. Retzius.)

The whole organ is further covered by a thick fibrillated membrane—the *tectorial membrane* (fig. 274)—which is attached at one edge to the upper surface of the limbus, falls over the crest, and rests on the rods of Corti and the hair-cells, thus converting the spiral groove into a canal. It will be necessary to describe more minutely these several parts of the organ of Corti.

Rods of Corti.—The inner and outer rods of Corti differ from one another in shape, although agreeing, for the most part, as regards the details of their structure. Each inner rod may be best compared in shape to a human ulna, the upper end of the rod being pretty accurately represented by the upper extremity of that bone, the shape of the olecranon and coronoid processes, as well as the concave articular surface between, being readily recognisable. The upper end of each of the outer rods, on the other hand, somewhat resembles the outline of a swan's head; the rounded part, which represents the back of the head, fitting into the concave surface on the head of the corresponding inner rod or rods, while the part which represents the bill projects outwards and is connected with the reticular lamina, aiding to form the first series of rings for the transmission of the auditory hairlets. Both inner and outer rods are more slender about the middle of their length and expand again below, so as to rest upon the basilar membrane by a somewhat widened foot. They are distinctly striated throughout their length (fig. 276).

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[1] Sydney Scott, Journ. Anat. and Physiol., July 1909.

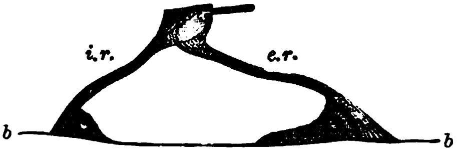

FIG. 275.—A PAIR OF RODS OF CORTI, FROM THE RABBIT'S COCHLEA; SIDE VIEW. Highly magnified. (E. A. Schäfer.)

b b, basilar membrane; *i.r.*, inner rod; *e.r.*, outer rod. The nucleated protoplasmic masses at the feet are also shown.

In some animals the head of the outer rod has an oval part free from fibres, staining with carmine more deeply than the remainder of the rod (pseudo-nucleus). A similar, but smaller, clear body, staining deeply with carmine, is seen in the head of the inner rod; the substance of the rod in its neighbourhood has a somewhat granular appearance (fig. 276).

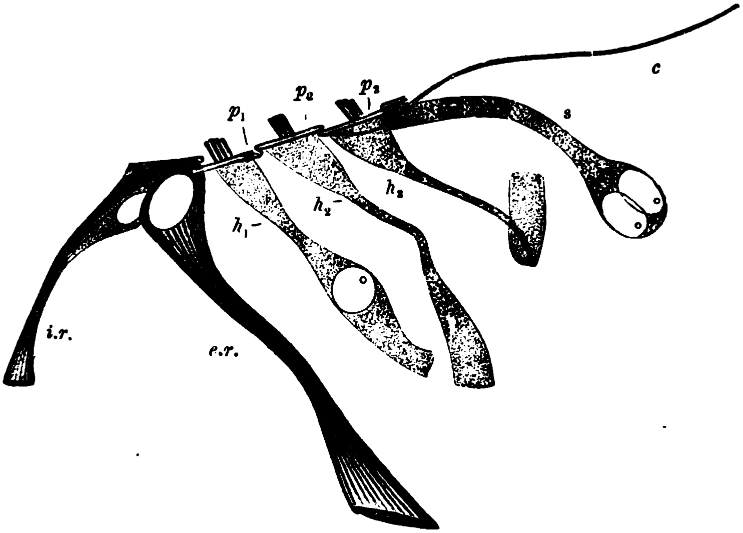

FIG. 276.—TEASED PREPARATION FROM GUINEA-PIG'S COCHLEA, SHOWING AN INNER AND OUTER ROD IN CONNEXION WITH OUTER HAIR-CELLS AND LAMINA RETICULARIS. (E. A. Schäfer.)

i.r., inner rod; *e.r.*, outer rod; h_1, h_2, h_3, hair-cells; *s*, one of the succeeding epithelial cells (cells of Hensen); *c*, a cuticular thread detached from a cell of Deiters; p_1, phalangeal process of outer rod; p_2, p_3, phalanges of lamina reticularis in section.

The inner rods are more numerous than the outer[1]; they are also more closely set and touch one another along their whole length, whereas the outer rods are only in contact laterally by their heads; finally, the outer rods are in all parts longer than the inner, and in the upper turns of the cochlea considerably so. How the two sets of rods are jointed together is not very clear. Certainly the individual rods have little, if any, independent movement; the feet are securely fixed to the basilar membrane, and the heads of adjacent rods are in close contact.

---

[1] According to Retzius, there are altogether in the human cochlea about 5,600 of the inner rods and nearly 4,000 of the outer ones. Spee counted over a given space of the basilar membrane 10 inner hair-cells, 18 inner rods, 14 outer rods, and 14 outer hair-cells in each series (Verhandl. d. Anat. Gesel. Anat. Anz. xx. 1902.)

Basilar cells.—In connexion with both inner and outer rods, there is seen a protoplasmic cell occupying the angle which the rod makes with the plane of the basilar membrane (figs. 274, 275). Sometimes these cells extend along the membrane until they come into contact, and they may, especially in young subjects, be seen to rise up and partly envelop each rod. They are the cells by and from which the rods have been formed.

Hair-cells and cells of Deiters.—The *inner hair-cells*, some 3,500 in number in all, are closely applied against two or three of the corresponding rods, the cells being considerably larger in diameter than the rods. Seen from above, they are oval and marked by a curved line, which is the line along which the hairlets are attached (fig. 278, *i.h.*). They are very like somewhat short columnar epithelium-cells with a rounded base (fig. 274). Beneath them, and extending also under the gradually decreasing columnar epithelium of the spiral groove, is a layer of irregularly columnar cells with large round nuclei, among which fine nerve-fibres run in a spiral direction. Around the top of each inner hair-cell is a ring of cuticular substance, which is connected with a slight projection on the head of the inner rod.

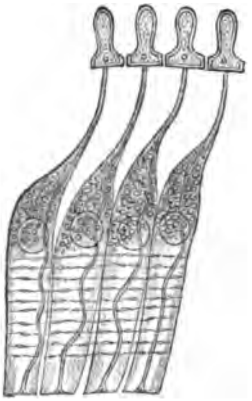

FIG. 277.—FOUR CELLS OF DEITERS, FROM THE RABBIT. Highly magnified. (Modified from G. Retzius.)

The phalangeal processes are shown, each expanding to form a phalanx of the reticular lamina. The varicose lines are spirally running nerve-fibrils.

The *outer hair-cells* are cylindrical at the upper end, where they fit into the rings of the reticular lamina and bear the hairlets. Lower down they are flattened from within out, at least in some animals (*e.g.* guinea-pig), so that, in profile, they look narrow, but broader when seen on the flat. These cells end below with a rounded extremity (fig. 274), extending about as far as to the narrowing part of Deiters' cells. The hairlets, as with the inner cells, are about twenty in number on each cell, and emerge along a curved line on the upper surface of the cell.

Van der Stricht describes the hairlets both here and in the maculæ as arising from a cuticular patch covering the free border of each cell. Scott, however, found them emerging from the cell-substance (see p. 325). Hensen described a clear oval body with a spiral fibre wound around it, occupying the part of each outer hair-cell next to the free extremity. In some animals another peculiarly staining body occurs near the base of the cell (Retzius, Held).

Cells of Deiters.—Beneath the hair-cells, and resting by a broad base upon the basilar membrane, certain other cells are found which are known as the *cells of Deiters* (figs. 274, 277). These, which are of a cylindrico-conical shape, rest by their bases upon the basilar membrane, and each one encloses in its substance a cuticular filament which is fixed below to that membrane. This filament is prolonged above in the tapering apex of the cell, between the hair-cells and in close contact with one of them, and is attached above to, or rather expands to form, one of the so-called phalanges of the reticular lamina: it is known as the *phalangeal process* of Deiters' cell (fig. 277). This cuticular filament may probably be regarded as the equivalent of the rod of Corti, the cell of Deiters to which it belongs representing the basilar cell which lies at the foot of each rod of Corti, and which in the young subject encloses the rod.

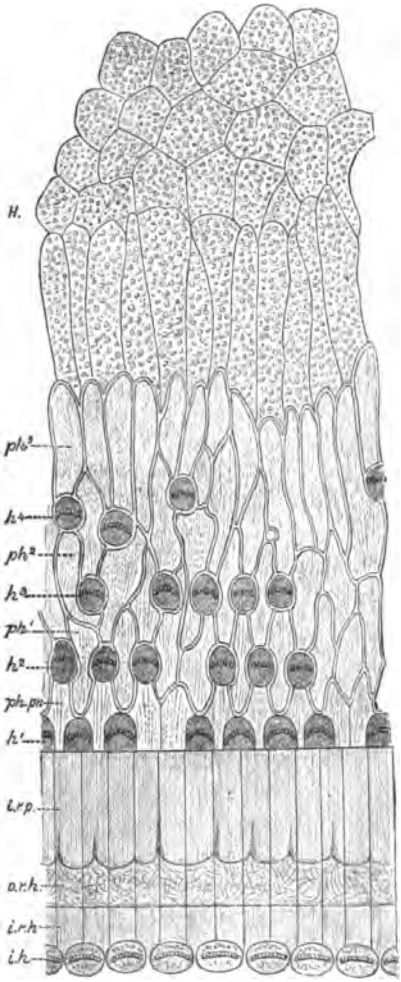

FIG. 278.—VIEW OF A SMALL PART OF THE ORGAN OF CORTI OF THE HUMAN COCHLEA FROM ABOVE, SHOWING THE LAMINA RETICULARIS. Much magnified. (G. Retzius.)

i.h, inner hair-cells, the hairlets being seen in section; *i.r.h*, heads of inner rods; *o.r.h*, heads of outer rods; *i.r.p*, 'olecranon' processes of inner rods; *ph.pr*, phalangeal processes of outer rods; ph^1, ph^2, ph^3, first, second, and third series of phalanges; h^1, h^2, h^3, h^4, first, second, third, and fourth series of outer hair-cells; *H*, cells of Hensen.

In most animals there are three series of outer hair-cells, but in man there are four series (fig. 274) except in the lowermost turn (fig. 269, *h.e*), and even five and six in the upper turns of the cochlea (Pritchard); but where they are more numerous they tend to be somewhat irregularly placed and intermittent. There are about 12,000 outer hair-cells in the human cochlea (Retzius). The columnar cells outside the hair-cells are much elongated and obliquely disposed, but become gradually shorter and more vertical as they pass into the simple cubical epithelium on the outer part of the basilar membrane.

Spaces filled with endolymph are seen both in the inner and outer hair-cell region, and communicate between the rods of Corti with the tunnel-space. The largest of these secondary spaces lies between the outer rods and the first row of outer hair-cells (Nuël). (See fig. 274.)

The cells which immediately succeed the hair-cells form in some animals a distinct swelling or arch outside the hair-cell region, from which and from the basilar membrane they may be separated by a considerable space occupied by endolymph. In the guinea-pig they contain a considerable number of fat-globules in the upper turns of the cochlea. They are sometimes known as the 'cells of Hensen,' whilst those which follow them and rest on the lateral half of the basilar membrane have been termed 'cells of Claudius.'

Reticular lamina (figs. 276, 278).—The net-like membrane which overlies the outer hair-cell region of the organ of Corti is composed of at least two rows of elongated fiddle-shaped structures termed 'phalanges,' which are united to one another and to the phalangeal processes of the outer rods in such a manner as to leave between them oblong apertures through which the free ends of the hair-cells with their semicircular rows of auditory hairs project. The phalanges, although they seem like rings, are in reality thin plates with thickened margins, and are to all appearance of a cuticular nature; the most external row of phalanges is in continuity with a cuticular tissue which lies over and between the cells of Hensen. Attached to the phalanges below are the phalangeal processes of the cells of Deiters (fig. 277). The lamina varies in extent with the number of rows of hair-cells. Where there are four or more of these, a corresponding increase in the number of rows of cells of Deiters and of phalanges is observed. The phalanges serve to isolate the hair-bearing ends of the auditory cells.

The **tectorial membrane** (figs. 269, 274, 279) is the last special structure which remains to be described in connexion with the organ of Corti. It arises, as before stated, on the limbus, close to the line of origin of Reissner's membrane. It overlies the projecting teeth at the edge of the limbus, and also the epithelium between them: this part of the membrane is thin and delicate, imperceptibly shading off towards the inner edge of attachment. As the membrane projects over the crest of the limbus, it swells out into a pad-like projection which roofs over the spiral groove, and rests upon the rods of Corti and contiguous structures. At its external edge, which is somewhat scalloped, the membrane is rounded. It ends abruptly over the outer hair-cell region, but in the apical turns it extends beyond this. According to Hardesty, it is only attached near its inner edge, the pad-like outer zone from the limbus to the outer edge being free and capable of independent vibration. The breadth of this free part varies in man from 120 μ in the basal turn to 240 μ in the apical turn (Ebner), but Hardesty found the variation in the pig considerably more than this (about 46 μ to 220 μ), and Kishi states that in man the membrane is three times as broad near the apex as near the base of the cochlea. It is also somewhat thicker in the upper turns than in the lower (Hardesty). The membrane is composed of fine fibrils imbedded in a glutinous matrix. The fibrils slant obliquely from the attachment of the membrane, taking a course outwards and towards the apex, and also curving round in the pad-like outer zone from its upper to its under surface, near which they again tend in a direction parallel with the surface. The upper surface of the membrane is

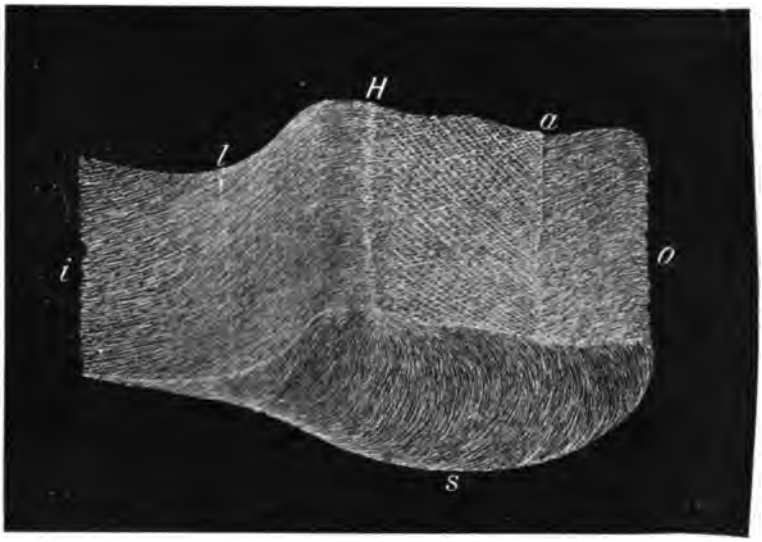

FIG. 279.—PORTION OF MEMBRANA TECTORIA OF PIG, DISPLAYING ITS UNDER SURFACE AND A CROSS-SECTION. (Hardesty.)

i, inner edge; *o*, outer edge; *s*, section of the membrane, showing the direction of its fibres (the letter is close to the convex upper surface); *l*, line impressed by edge of limbus; *H*, band of Hensen; *a*, outer edge of latticed or accessory membrane of Hardesty.

convex, the lower concave; but the under surface of the pad-like part is adapted to the upper surface of the organ of Corti, on which it appears to rest. The under surface is marked by two lines which are parallel to its edges. One of these (fig. 279, *l*) seems to be caused by the impression of the edge of the limbus and marks off the attached part or *inner zone* from the projecting part or *outer zone* of the membrane. The other (H), first noticed by Hensen, appears to be the optical effect of the peculiar arrangement of the fibres of the membrane, some of which sweep round with an outward and others with an inward curve, the two groups interlocking along a band-like zone on this surface. The situation of this *band of Hensen* is just over the rods of Corti (Hardesty). The membrana tectoria is very elastic, although chemically it contains no elastin. After fixation it tends to split in the direction of the constituent fibres. A reticular outermost zone, which has sometimes been described as extending beyond the hair-cell region, does not exist, according to Hardesty. But this observer describes a delicate lattice-like *accessory tectorial membrane* lying on the under surface beyond the band of Hensen and not quite reaching the outer edge of the chief membrane except in the basal turn.[1]

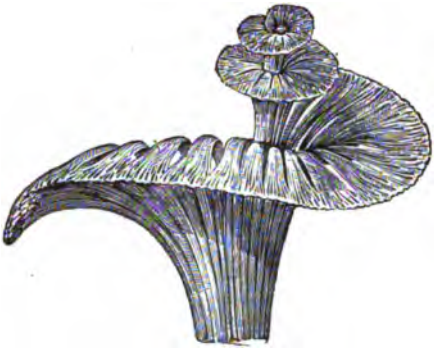

FIG. 280. — GENERAL VIEW OF THE MODE OF DISTRIBUTION OF THE COCHLEAR NERVE, ALL THE OTHER PARTS HAVING BEEN REMOVED. (Arnold.)

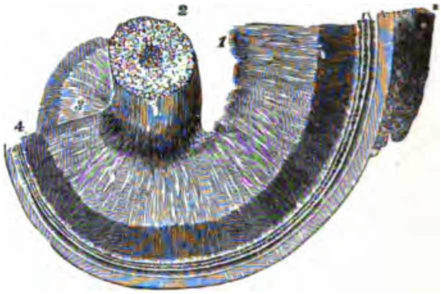

FIG. 281. — DISTRIBUTION OF THE COCHLEAR NERVES IN THE SPIRAL LAMINA. (Henle.)

This figure shows part of the modiolus and spiral lamina, viewed from the base, showing the plexiform arrangement of the cochlear nerves: 1, filaments of the nerve issuing from the tractus spiralis foraminulentus; 2, branches of the nerve entering the central canal of the modiolus; 3, wide plexus in the bony lamina spiralis; 4, close plexus at its border.

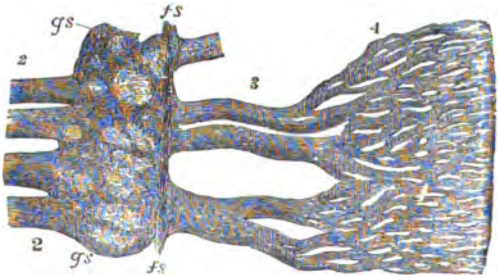

FIG. 282.—PART OF THE NERVES EXTRACTED AND MORE HIGHLY MAGNIFIED. (Henle.)

2, twigs of the nerve from the modiolus close to the lamina spiralis ossea; *gs*, spiral ganglion; *fs*, nerve-fibres running spirally along the outer part of the ganglionic swelling; 3, wide plexus; 4, close plexus of nerve-fibres as in fig. 281.

Nerves of the cochlea.—The branch of the acoustic nerve which goes to the cochlea is shorter, flatter, and broader than any of the other branches. It perforates the bone by groups of minute foramina at the bottom of the internal meatus, below the opening of the facial canal. These groups are arranged in a shallow spiral furrow (tractus spiralis foraminosus) in the centre of the base of the cochlea; they lead into small bony canals, which first follow the direction of the axis of the cochlea, through the modiolus (figs. 266, 267, 280), and then radiate outwards between the plates of the bony spiral lamina (fig. 281). In the centre of the spiral tract is a larger foramen which leads to the central canal of the modiolus. Through this foramen and canal the filaments for the last half-turn of the spiral lamina are conducted; whilst the first two turns are supplied by the filaments which occupy the smaller foramina and bent canals. Near the root of the spiral lamina the nerve-fibres pass outwards through a spirally wound ganglionic cord (*ganglion spirale*), situated in the spiral canal of the modiolus. The cells of this ganglion are bipolar, and each nerve-fibre has one of the cells interpolated in its course. From the peripheral side of the ganglion, the fibres, having resumed their medullary sheath, pass onwards with a plexiform arrangement, at first in distinct but anastomosing cords (fig. 282, 3), contained in separate canals in the bony lamina, but afterwards spreading out into a stratum of intermingling fibres, to be again gathered up, near the edge of the osseous lamina, into conical bundles which turn abruptly upwards, and, passing through the elongated apertures previously described (fig. 270, *p*), lose their medullary sheath, and enter the epithelium in the region of the inner hair-cells (fig. 274). Some of the nerve-fibres end here, ramifying with a spiral course amongst the bases of the inner hair-cells; others are continued as fine threads between the inner rods, and form a second spiral band close to the outer side of these and in contact with the protoplasmic cell which ensheaths them. Other fibres pass across the tunnel of Corti between the rods and enter the region of the outer hair-cells. Here the fibres branch, and, altering their direction, run spirally parallel with the successive series of hair-cells (fig. 283). They rest against the corresponding cells of Deiters, and in man form a bunch of spirally running fibres immediately below the expanded part of each hair-cell (fig. 274). They form, therefore, altogether five or six spiral strands of fibrils, which lie between the epithelium-cells of the organ of Corti. In most animals they are less grouped together and more distributed along the length of each cell of Deiters, but with the same spiral arrangement and in the same relative position.

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[1] Hardesty, Amer. Journ. of Anat. viii. 1908. This paper contains the literature of the subject up to that date.

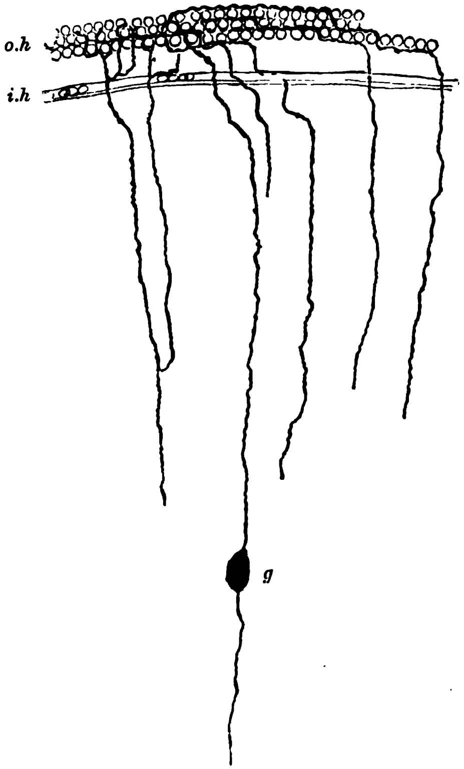
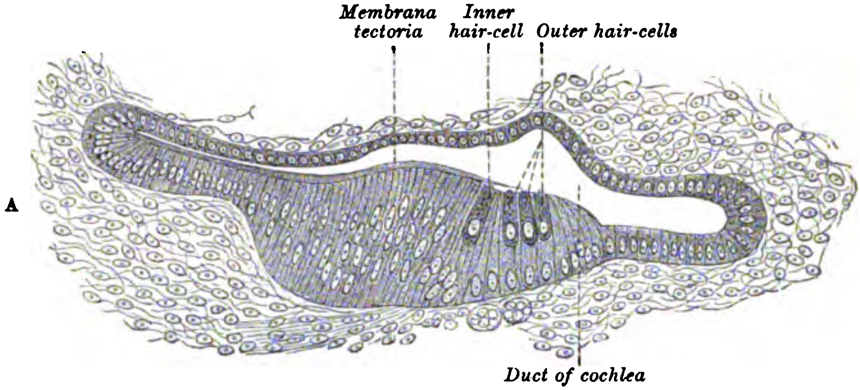


FIG. 288.—ENDING OF NERVE-FIBRES IN THE COCHLEA. Shown by Golgi's method. (G. Retzius.)

g, a cell of the spiral ganglion; *i.h.*, inner hair-cells; *o.h.*, outer hair-cells, with the nerve-fibres running spirally between the cells.


Membrana tectoria
Inner hair-cell
Outer hair-cells
A
Duct of cochlea

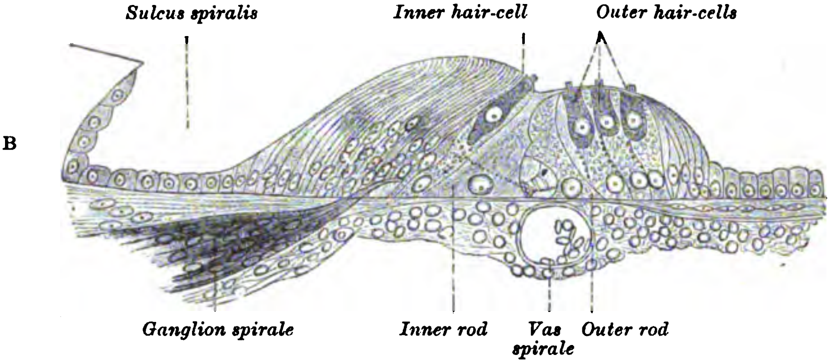

Sulcus spiralis
Inner hair-cell
Outer hair-cells
B
Ganglion spirale
Inner rod
Vas spirale
Outer rod

FIG. 284.—TWO STAGES IN THE DEVELOPMENT OF THE ORGAN OF CORTI OF THE CAT. (G. Retzius.)

In the first of the two stages represented (A) the hair-cells are differentiated; in the second (B) the rods of Corti are also beginning to be formed, and the nerve-fibres have reached the organ of Corti, and are already running spirally below the hair-cells.

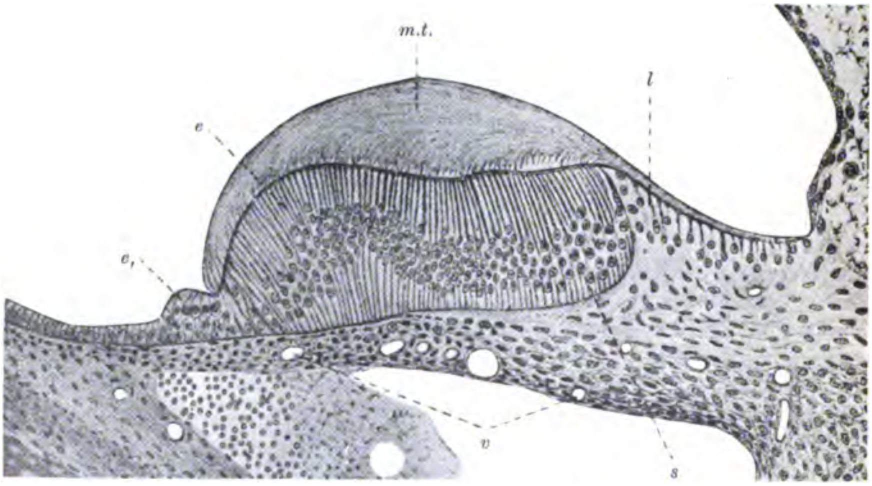


FIG. 285.—SECTION OF COCHLEA OF EMBRYO PIG. (Hardesty.)

e, epithelium of greater pad; e′, epithelium of lesser pad; l, limbus; s, sulcus spiralis; v, vessels; m.t., membrana tectoria developing from cells of greater pad.

Vessels of the cochlea.—The branches of the internal auditory artery to the cochlea, twelve or fourteen in number, arising at the bottom of the internal auditory meatus, traverse small canals in the modiolus and bony lamina spiralis, and also pass to the outer wall of the cochlea, forming at the root of the septum, between the turns of the cochlear tube, a spirally arranged glomerulus-like arterial plexus, which sends vessels to the subjacent stria vascularis and to the periosteum lining the adjacent scalæ (Schwalbe). The vessels do not anastomose across the membrana basilaris. The bony cochlea also receives through the fenestra rotunda a twig from the stylomastoid branch of the occipital artery.

The veins issue from the grooves of the cochlear axis, and join the veins of the vestibule and semicircular canals at the base of the modiolus. A small sinus-like vein passes through the aqueductus cochleæ, from the lowermost turn of the cochlear tube, and joins the commencement of the internal jugular vein.

Development of the organ of Corti.—The organ of Corti is at first composed of columnar epithelium-cells forming part of the layer of ectoderm which lines the whole of the membranous labyrinth (see vol. i.). The cells form two prominences, an inner larger and an outer smaller. After a time certain of the cells begin to be differentiated from the rest as inner and outer hair-cells (fig. 284, A). Subsequently the rods of Corti become formed by a transformation of some of the columnar cells belonging to the smaller prominence, and the cells of Deiters also become distinguishable (fig. 284, B). In the meantime the epithelium of the vascular stria, which was at first similar to that of the rest of the canal, becomes pigmented and vascularised, and the remaining epithelium of the cochlear canal is also gradually acquiring the form and character by which its various parts are distinguished. The membrana tectoria appears to be formed as a cuticular deposit or secretion from the larger epithelial prominence, which at first fills the spiral sulcus (fig. 284, A; fig. 285).[1]

Measurements of some of the parts of the cochlea.—The following numbers (from Retzius[2]) show the average dimensions in millimetres of various parts of the human cochlea:

Cochlear canal, breadth, basal turn	0·45
„ „ „ middle „	0·77
„ „ „ apical „	0·80
„ „ extreme length	35·00
Reissner's membrane, breadth, basal turn	0·81
„ „ „ middle „	0·88
„ „ „ apical „	0·85
Limbus laminæ spiralis, breadth, basal turn	0·24
„ „ „ „ middle „	0·23
„ „ „ „ apical „	0·22
Rods of Corti, space between attachment of feet, basal turn	0·048
„ „ „ „ „ „ middle „	0·081
„ „ „ „ „ „ apical „	0·09
„ „ height of arch, basal turn	0·028
„ „ „ „ middle „	0·045
„ „ „ „ apical „	0·049
„ „ length of inner rods	0·048–0·07
„ „ „ outer rods	0·06–0·1
Hair-cells, length of inner	0·018–0·024
„ „ outer	0·03–0·04
„ „ projecting hairlets	0·005
Membrana tectoria, breadth	0·28–0·34
„ „ extreme thickness	0·025
Basilar membrane, breadth from habenula perforata to lig. spiral., basal turn	0·21
„ „ „ „ „ middle „	0·34
„ „ „ „ „ apical „	0·36
„ „ breadth from habenula perforata to feet of outer rods, basal turn	0·075
„ „ „ „ „ middle „	0·12
„ „ „ „ „ „ apical „	0·126

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[1] Van der Stricht, Arch. de Biol. xxiii. 1908; Hardesty, *op. cit.*

[2] Das Gehör-Organe, 1884. Cf. Gray, 'The Labyrinth of Animals,' 1907, some of whose measurements differ from these.

THE NOSE.

THE nose is the special organ of the sense of smell. It has also other functions to fulfil; for, communicating freely with the cavities of the mouth and lungs, it is concerned in respiration, voice, and taste; and by means of its muscles it assists in expression.

The nose forms a prominence composed of bone and hyaline cartilage, with certain muscles, and a general covering of integument. At its lower extremity or base the nostrils (anterior nares) open downwards. Its upper end is the *root*, the rounded or flattened ridge along its middle is termed the *dorsum*, and this ends below in the *point* of the nose. The upper or bony part of the dorsum is often spoken of as the *bridge*; it frequently forms an angle with the cartilaginous part (aquiline type). The root springs from below the glabella of the frontal bone, with which it usually forms a more or less marked angle, so that the nose appears to spring from a groove; if this groove is absent, and the line of the dorsum is continuous with the plane of the forehead, the Grecian type of nose is produced. The sides of the nose, which form an open angle (*naso-facial angle*) with the general anterior surface of the face, diverge from the dorsum at an increasing angle as we trace them down from the root; the nose is therefore broadest below at the nostrils. This lowest part of the lateral wall is slightly bulged outwards, and is separated from the rest by a slight groove: it is known as the *ala* of the nose, and is mobile, its form being capable of alteration by the action of certain muscles, which thereby dilate or contract the nostrils. A median partition (*septum nasi*) divides the interior of the nose into two approximately equal parts, the *right and left nasal fossæ*. These open behind into the pharynx by the posterior nares (choanæ), and below on to the exterior by the anterior nares, and communicate with hollows in the neighbouring bones (ethmoid, sphenoid, frontal, and maxillary). The framework of the septum is formed posteriorly of bone and anteriorly of cartilage. It is covered on each side in the whole of its extent by mucous membrane, except near the anterior nares, where the mucous membrane is replaced by skin. This part of the septum forms the mesial boundary or separation between the anterior nares; in the rest of their extent the anterior nares are bounded by the curved free margin of the alæ.

According to the degree of the development and complexity of the nasal fossæ and of the olfactory lobes of the cerebrum mammals are divided by Turner into the three subdivisions of *macrosmatics*, including rodents, carnivora, marsupials, and most mammals; *microsmatics*, including man and most Primates, Monotremes, and some Cetacea; and *anosmatics*, including certain Cetacea (*e.g.* porpoise).

The skin of the nose is studded, particularly in the grooves of the alæ or outer walls of the nostrils, with numerous small openings, which lead to sebaceous follicles. Within the margin of the nostrils are a number of short, stiff, and slightly curved hairs—*vibrissæ*—which grow from the inner surface of the alæ and septum nasi.

As is well known, the nose presents great variety in size and shape in different individuals. Into most of these it is unnecessary here to enter, but there is one kind of variation which is of considerable anthropological importance—viz. the extent of lateral expansion of the anterior nares as compared with the total length of the organ. This relationship is expressed by the cephalometric nasal index $\left(\frac{\text{greatest breadth} \times 100}{\text{length measured vertically}}\right)$. It is found that in the white races of mankind the nasal index is below 70; in the black races (African, Australasian) it is 85 and upwards; in the yellow races (Asiatic, American-Indians, Eskimo) from 70 to 85 (Topinard).

The blood-vessels of the outer nose are branches of the ophthalmic and facial. The lymphatics pass to the submaxillary lymphatic glands. The sensory nerves are branches of the first and second divisions of the fifth, and the motor nerves are derived from the facial. These are described under 'The Nerves.'

CARTILAGES OF THE NOSE.

The *cartilage of the septum* (figs. 286, 289, 290) is irregularly quadrilateral in form, and is thicker at the edges than near the centre. It is placed nearly vertically in the median plane of the nose, but often with an inclination to one or other side. The posterior margin is fixed to the lower and fore part of the central plate of the ethmoid bone; and the lower margin is received into the groove of the vomer, and rests anteriorly on the incisor crest of the maxillæ. The anterior margin of the cartilage, thickest above, is firmly attached to the back of the nasal bones near their line of junction, and below these bones it forms a well-marked convexity which reaches nearly to the tip of the nose (fig. 289). The upper part of this convex border is continuous with the lateral nasal cartilages, while its lower part is separated by the great alar cartilages from the tip of the nose and from the base of the internarial septum. In young subjects it is prolonged back to the body of the presphenoid bone; and in many adults an irregular thin band remains between the vomer and the central plate of the ethmoid (*processus posterior s. sphenoidalis*, fig. 289). The *vomeronasal cartilages* or *cartilages of Jacobson*, are two small longitudinal strips of cartilage which lie along the lower border of the cartilage of the septum, attached to the vomer and maxillæ. They are not always distinct from the cartilage of the septum, being

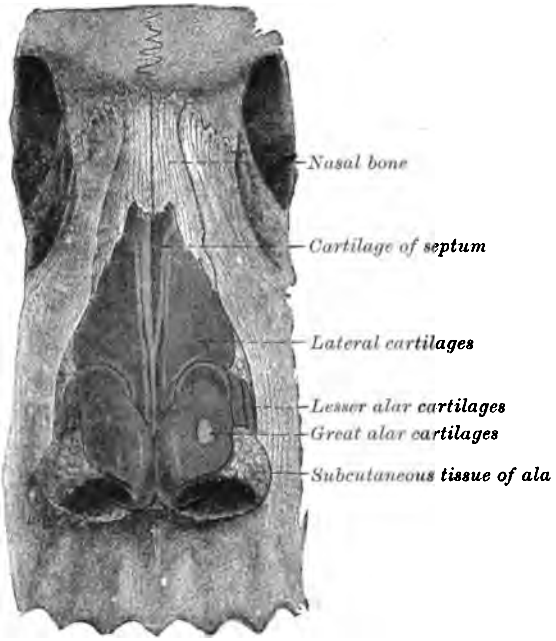

Fig. 286.—Front view of the cartilages of the nose. (Arnold.)

often represented by lateral processes of its lower border. They are relatively better developed in the embryo and in many of the lower mammals conformably with the greater extent of development of the organ of Jacobson (see p. 351), which, in some animals, they partly enclose. In man the rudimentary organs of Jacobson are situated higher up in the septum than these cartilages.

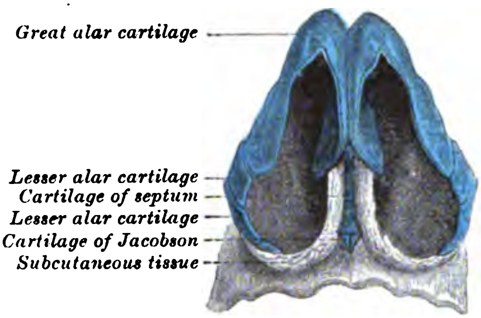
Great alar cartilage
Lesser alar cartilage
Cartilage of septum
Lesser alar cartilage
Cartilage of Jacobson
Subcutaneous tissue

FIG. 287.—VIEW OF THE CARTILAGES OF THE NOSE FROM BELOW. (Arnold.)

The *lateral cartilages* (figs. 286, 288, 290) are situated in the middle part of the projecting portion of the nose, immediately below the free margin of the nasal bones. Each is flattened and triangular in shape, with one surface looking outwards, and the other inwards towards the nasal cavity. The anterior margin, thicker than the posterior, is continuous with the edge of the cartilage of the septum above, but is separated therefrom by a small fissure below. The posterior edge is closely attached to the free margins of the maxilla and of the nasal bone, and the inferior margin turns inwards, forming a fold termed the *plica vestibuli*, which with the opposite portion of the septum bounds a slit-like opening between the vestibule of the nose and the nasal cavity proper.

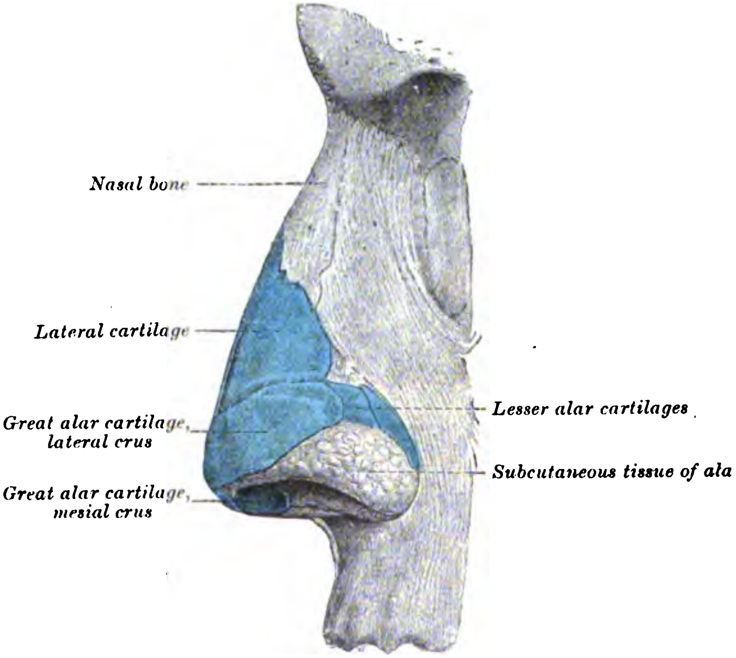
Nasal bone
Lateral cartilage
Great alar cartilage, lateral crus
Great alar cartilage, mesial crus
Lesser alar cartilages
Subcutaneous tissue of ala

FIG. 288.—LATERAL VIEW OF THE CARTILAGES OF THE NOSE. (Arnold.)

The *great alar cartilages* or *cartilages of the aperture* (figs. 286, 287, 288) are thinner than the preceding, below which they are placed, and are characterised

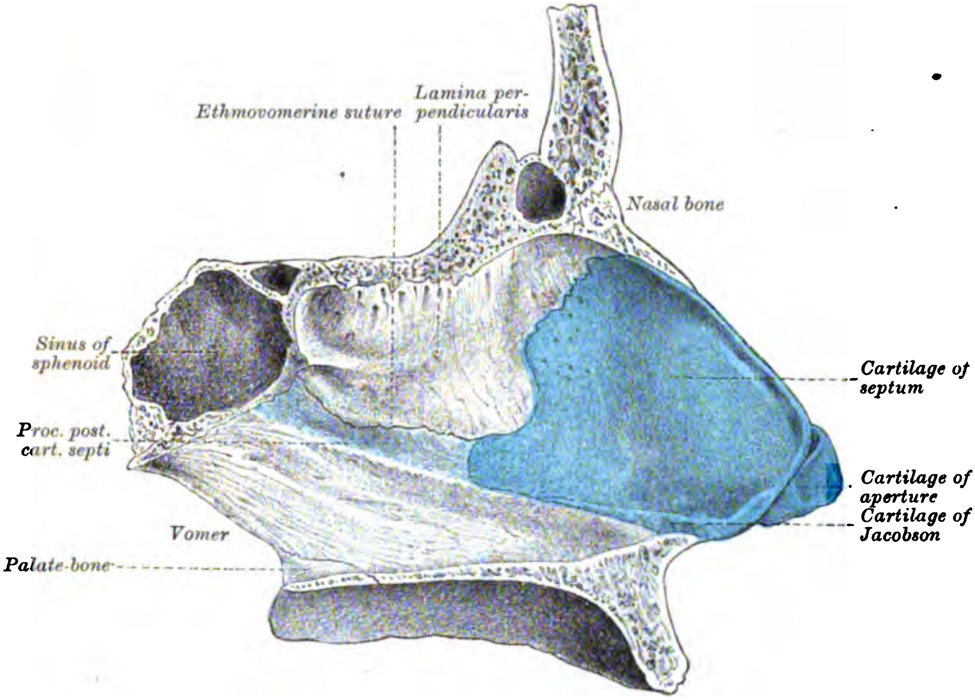
Lamina perpendicularis
Ethmovomerine suture
Nasal bone
Sinus of sphenoid
Cartilage of septum
Proc. post. cart. septi
Cartilage of aperture
Cartilage of Jacobson
Vomer
Palate-bone

FIG. 289.—OSSEOUS AND CARTILAGINOUS SEPTUM OF THE NOSE, SEEN FROM THE SIDE. (Arnold.)

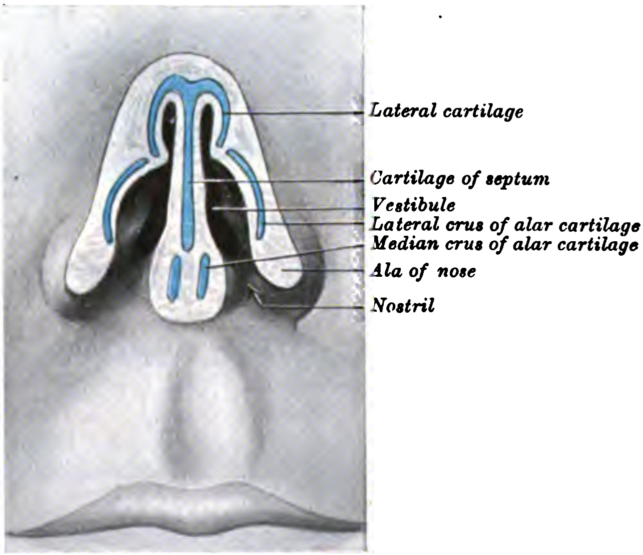
Lateral cartilage
Cartilage of septum
Vestibule
Lateral crus of alar cartilage
Median crus of alar cartilage
Ala of nose
Nostril

FIG. 290.—CORONAL SECTION OF THE CARTILAGINOUS PART OF THE EXTERNAL NOSE PASSING FROM THE DORSUM IN FRONT OF THE NASAL BONES DOWNWARDS THROUGH THE NOSTRILS. Natural size. (J. Symington.)

by their peculiar curved form. Each consists of an elongated plate, so bent upon itself as to pass in front and on each side of the nostril to which it belongs, and by this arrangement serves to keep it open. The outer portion (*lateral crus*) is somewhat oval and flattened, or irregularly convex externally. Behind, it is attached to the margin of the maxilla by tough fibrous membrane, enclosed in which there is usually to be met with either a prolongation backwards of the posterior angle of the cartilage, or two or three separate cartilaginous nodules (*cartilagines minores*) (figs. 286, 287); above, it is fixed, also by fibrous membrane, to the lateral cartilage, and to the lower and fore part of the cartilage of the septum. Towards the middle line it is curved backwards (*median crus*) (fig. 287), bounding a deep median groove, at the bottom of which it meets with its fellow of the opposite side, and continues to pass backwards, lying in the columna nasi, below the level of the cartilage of the septum. This inner part of the cartilage of the aperture is narrow, curls outwards, and ends in a free rounded margin which projects outwards. The ala of the nose, like the lobule of the ear, is formed of thickened skin with subjacent tissue, and is unsupported by cartilage.

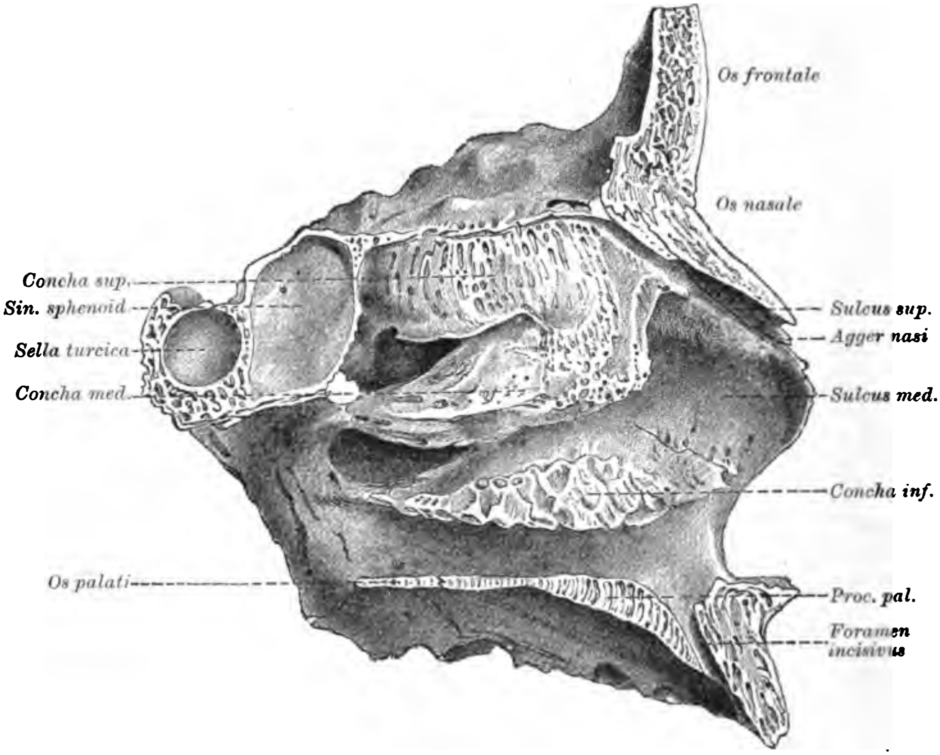

FIG. 291 —VIEW OF THE LATERAL WALL OF THE LEFT NASAL FOSSA AS IT APPEARS IN THE MACERATED SKELETON. (Arnold.)

NASAL FOSSÆ.

The nasal fossæ are, as already stated, the cavities which occupy the interior of the nose and effect a communication between the exterior and the pharynx. They have been described in the section 'Osteology,' as they exist in the skeleton, but they are much narrower in the living condition owing to the thickness and vascularity of the lining membrane, which also covers over many of the apertures seen in the macerated bone. These differences are well exemplified by comparing fig. 291, which represents the lateral wall of the left nasal fossa in the macerated condition, with fig. 292, which shows the right nasal fossa as it appears when still covered by mucous membrane. In coronal section each nasal fossa is very irregular and elongated, narrower above than below. The upper part is almost slit-like in section (figs. 294, 295), but about halfway towards the base—*i.e.* immediately below the free edge of the middle turbinal (see below)—the fossa expands, so that this lower part is markedly broader than the upper part, which is often spoken of as the *pars respiratoria*, the upper narrow part being referred to as the *pars olfactoria* (or *olfactory cleft*). The mesial wall and floor of each fossa are smooth, but the lateral wall is complicated by a series of lamellar prominences running in a sagittal direction and projecting into the cavity; these prominences, which are formed by the turbinate processes of the ethmoid bone and by the inferior turbinate bone covered by mucous membrane, are the *turbinate bodies*, or *turbinals* (*conchæ*). Each turbinal has an upper attached border and a lower

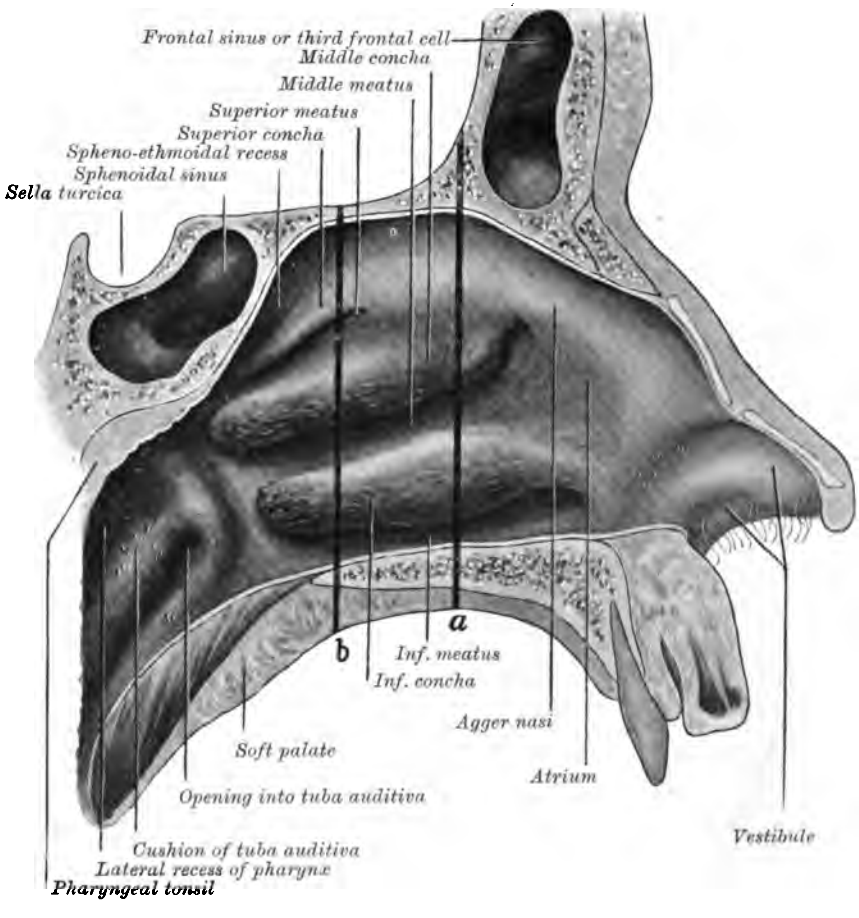
Frontal sinus or third frontal cell
Middle concha
Middle meatus
Superior meatus
Superior concha
Spheno-ethmoidal recess
Sphenoidal sinus
Sella turcica
a
b
Inf. meatus
Inf. concha
Agger nasi
Soft palate
Atrium
Opening into tuba auditiva
Vestibule
Cushion of tuba auditiva
Lateral recess of pharynx
Pharyngeal tonsil

FIG. 292.—VIEW OF LATERAL WALL OF RIGHT NASAL CAVITY OF ADULT MALE. Natural size. (J. Symington.)

The lines (*b*) and (*a*) indicate the position of the coronal sections shown in figs. 294 and 295.

usually rolled free border, a mesial or septal surface more or less convex, and a lateral surface generally concave and looking towards a meatus.

The following are the average dimensions of the nasal fossæ (Thane):

Greatest vertical measurement (at fore-part of cribriform plate)	44 mm.
Greatest sagittal measurement (along floor from posterior margin of hard palate to anterior extremity of nostril)	73 mm.
Sagittal measurement of osseous part of floor	44 mm.
Least sagittal measurement (close below cribriform plate)	35 mm.
Greatest coronal measurement (near floor)	12 mm.
Least coronal measurement (near roof)	2 mm.
Coronal measurement (just anterior to inferior turbinal)	4 mm.

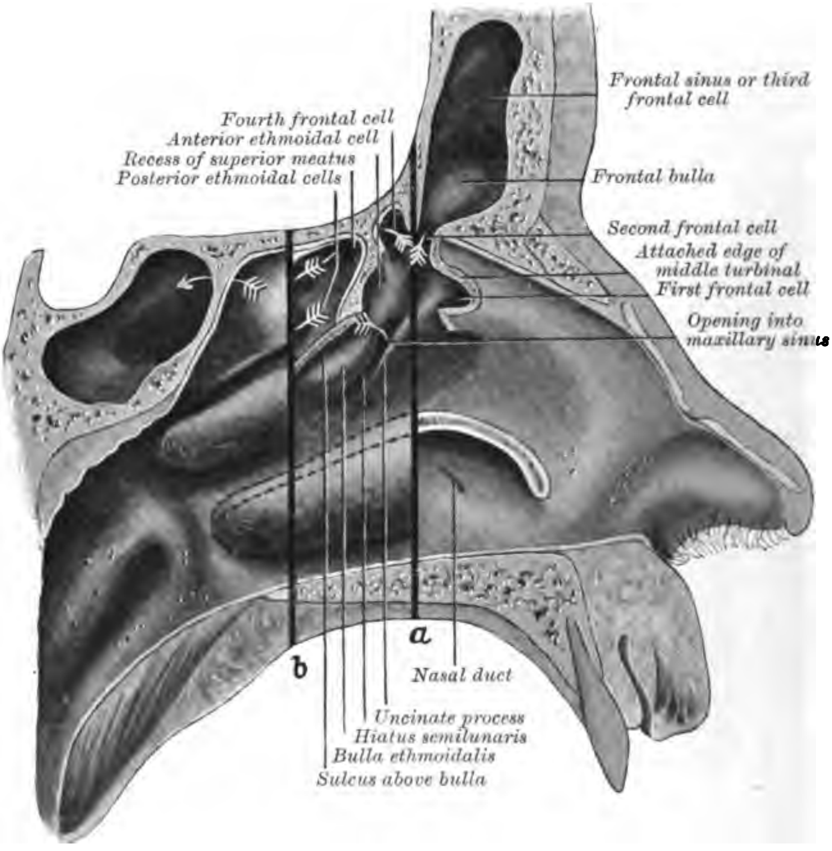
Fourth frontal cell
Anterior ethmoidal cell
Recess of superior meatus
Posterior ethmoidal cells
Frontal sinus or third frontal cell
Frontal bulla
Second frontal cell
Attached edge of middle turbinal
First frontal cell
Opening into maxillary sinus
a
b
Nasal duct
Uncinate process
Hiatus semilunaris
Bulla ethmoidalis
Sulcus above bulla

FIG. 293.—VIEW OF LATERAL WALL OF RIGHT NASAL CAVITY OF ADULT MALE. Natural size. (J. Symington.)

This drawing is from the same specimen as fig. 292, but parts of the superior, middle, and inferior conchæ have been removed to show the lateral wall of the meatuses and the openings connected with them. Arrows have been passed from the spheno-ethmoidal recess into the sphenoidal sinus, from the superior meatus backwards into the posterior ethmoidal cell, from the hiatus semilunaris into the maxillary sinus, and from the infundibulum into the third and fourth frontal cells. Opposite line (*b*) there was a direct opening of the maxillary sinus into the middle meatus. The lines (*b*) and (*a*) as in fig. 292.

The turbinals on the lateral wall of each fossa are usually described as three in number—viz. two on the lateral mass of the ethmoid, which are known as the superior and middle turbinals (superior and inferior ethmoidal conchæ), and one, the inferior turbinal, on the maxillary bone (maxillary concha). Each concha overhangs and partially separates from the general cavity of the fossa a groove-like space, which is known as the corresponding *meatus* (*superior*, *middle*, or *inferior* as the case may be). Very frequently there is a small meatus placed above and behind the superior meatus and bounded above by a *concha suprema*. The supreme meatus, when present, has usually one of the posterior ethmoidal cells opening into it, and in the superior meatus there are usually two apertures for two other cells belonging to this group.

The middle turbinal or concha is large, and overhangs a correspondingly large *middle meatus*, which can only be properly seen on cutting away the concha (fig. 293). The free border of the concha is 40 mm. to 45 mm. long. It sometimes descends almost vertically for about 10 mm. and then turns abruptly backwards, but more frequently the two portions (vertical and horizontal) join one another without any marked angular projection. The attached border ascends in front nearly to the roof of the nose and then curves downwards and backwards. On removing this concha, the lateral wall of the meatus is seen to be marked by a deep curvilinear depression (*hiatus semilunaris*, Zuckerkandl) extending from behind upwards and forwards, and bounded below and in front

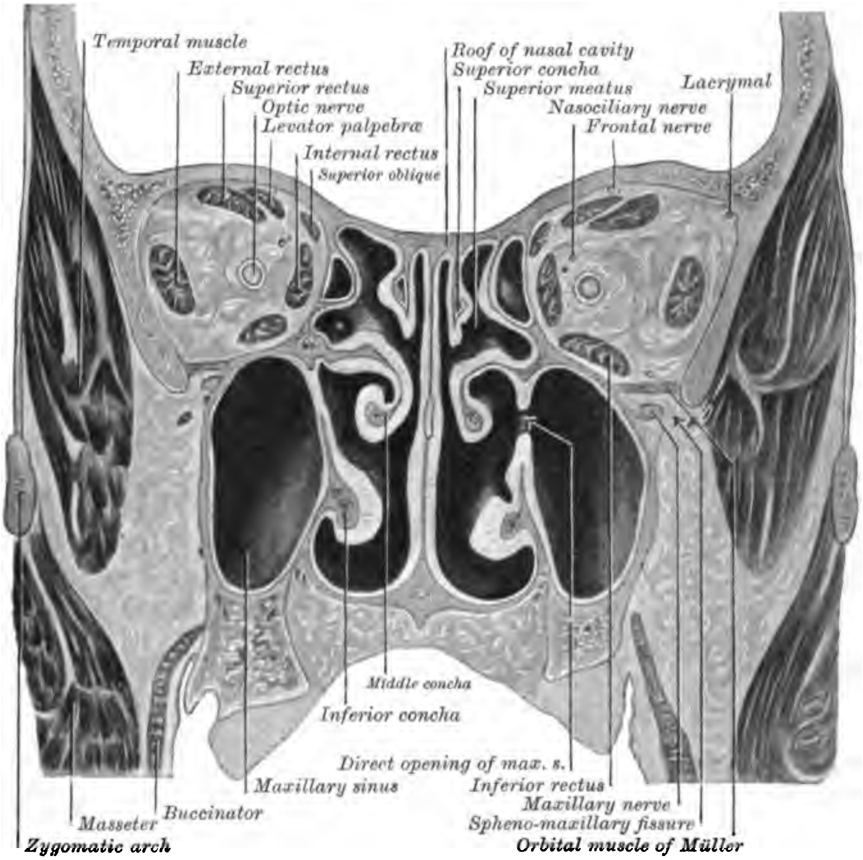
Temporal muscle
External rectus
Superior rectus
Optic nerve
Levator palpebræ
Internal rectus
Superior oblique
Roof of nasal cavity
Superior concha
Superior meatus
Lacrymal
Nasociliary nerve
Frontal nerve
Middle concha
Inferior concha
Direct opening of max. s.
Maxillary sinus
Inferior rectus
Maxillary nerve
Masseter
Buccinator
Spheno-maxillary fissure
Zygomatic arch
Orbital muscle of Müller

FIG. 294.—CORONAL SECTION OF HEAD OF ADULT MALE 5 CM. IN FRONT OF THE EXTERNAL AUDITORY MEATUS; VIEWED FROM BEHIND. Natural size. (J. Symington.)

The position of this section on the lateral wall of the left nasal cavity is shown in line (*b*) in figs. 292, 293.

by a thin sharp border (*processus uncinatus*), and behind and above by an oval prominence, often very strongly marked, termed the *bulla ethmoidalis*. This hiatus leads into a space termed the infundibulum, which lies external to the uncinate process. The maxillary sinus opens into the floor of the infundibulum, and one or two small air-cells (infundibular cells) are found on its outer wall. Anteriorly the meatus is prolonged upwards and forwards into a gradually narrowing funnel-shaped passage termed the frontal recess (infundibulum of some authors). The groove above the bulla ethmoidalis has one or two apertures for the anterior ethmoidal cell and one for the cell of the bulla, when present. The frontal recess may be prolonged upwards as the naso-frontal duct directly into the frontal sinus, or this duct may be an upward extension of the hiatus semilunaris. These two conditions are known as the direct and indirect mode

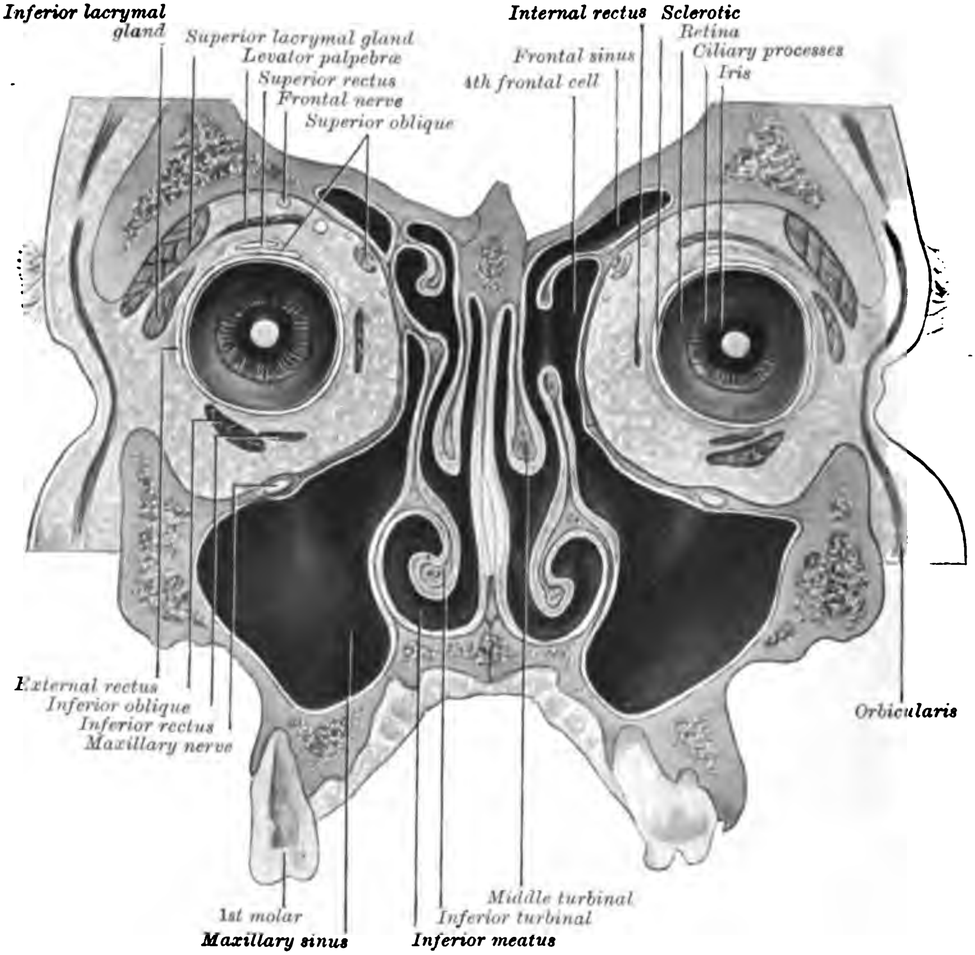
Inferior lacrymal gland
Superior lacrymal gland
Levator palpebræ
Superior rectus
Frontal nerve
Superior oblique
Internal rectus
Sclerotic
Retina
Ciliary processes
Iris
Frontal sinus
4th frontal cell
External rectus
Inferior oblique
Inferior rectus
Maxillary nerve
Orbicularis
1st molar
Maxillary sinus
Middle turbinal
Inferior turbinal
Inferior meatus

FIG. 295.—CORONAL SECTION OF THE HEAD OF AN ADULT MALE 7 CM. IN FRONT OF THE EXTERNAL AUDITORY MEATUS, VIEWED FROM BEHIND. Natural size. (J. Symington.)

The position of this section on the lateral wall of the left nasal cavity is shown in line (*a*) in figs. 292, 293.

of formation of the frontal sinus (Killian). In addition to the frontal sinus there are generally three frontal cells connected with the frontal recess. One passes forwards on the inner side of the nasal process of the maxillary bone, another lies internal to the lacrymal bone, and a third is posterior to the frontal sinus and often extends backwards and outwards into the roof of the orbit (see fig. 293).

The part of the middle meatus which lies below the level of the middle turbinal is roughly triangular in shape, with the base of the triangle directed forwards. In elderly subjects there is sometimes an accessory orifice of the maxillary sinus on its lateral wall. The meatus expands in front of the middle turbinal into a nearly smooth-walled chamber which communicates through the vestibule with the anterior nares; this chamber is known as the *atrium* of the middle meatus. On the outer wall above the atrium a low ridge (figs. 291, 292) may usually be detected passing downwards and forwards from the anterior attachment of the middle turbinal. This ridge (*agger nasi* of H. Meyer), which is seen also in the macerated bone (fig. 291), is the rudiment of a well-developed turbinal (*nasoturbinal*), which is met with in most mammals (Schwalbe). It is usually better marked in the fœtus and new-born child, in which it is seen to be continued below and behind into the uncinate process of the ethmoid, which forms the lower and anterior boundary of the hiatus semilunaris (Seydel). The groove above the agger nasi leads to the olfactory part of the nose, and is termed *sulcus olfactorius*.

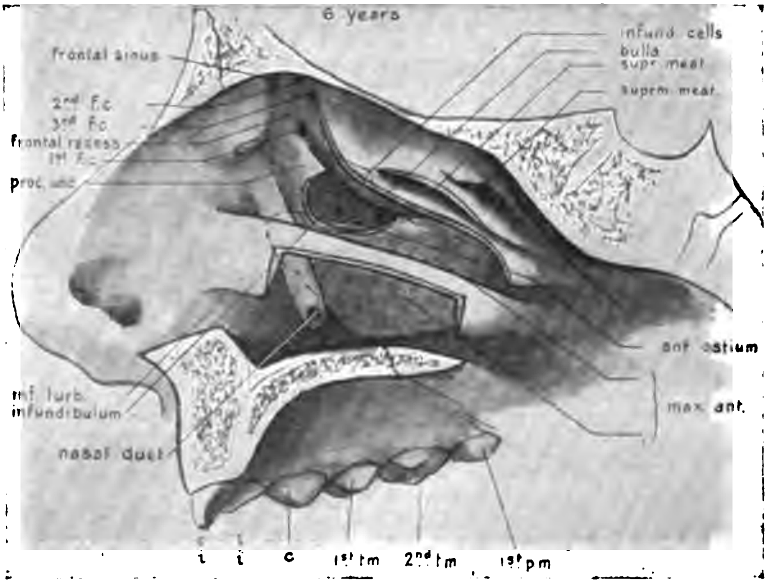

Fig. 296.—A DISSECTION OF THE LATERAL WALL OF THE RIGHT NASAL CAVITY IN A BOY SIX YEARS OLD. Natural size. (J. Symington.)

The greater portions of the middle and inferior turbinals and the uncinate process are removed. The dotted line on the nasal duct is intended to show the anterior limit of the maxillary sinus. (From a dissection by Dr. P. T. Crymble.)

The ethmoidal conchæ are less numerous in man than in many other mammals, but according to Killian there may be as many as six present in the human fœtus, each of which is divisible into an anterior ascending and a posterior descending limb. Some of these fœtal conchæ tend to disappear, and in extreme cases the number may be reduced to two, commonly called the superior and middle conchæ, but in fully 50 per cent. another, the supreme, remains

throughout life. The reduction in the number of conchæ is apparently produced by a process of fusion which involves mainly the ascending limbs of the conchæ and affects especially the upper and posterior conchæ. The naso-turbinal is probably represented in man by the agger nasi and the uncinate process.[1]

In the lower meatus, which lies between the inferior turbinal and the floor of the fossa, is the inferior orifice of the nasal duct. The duct runs obliquely through the mucous membrane and opens by a slit-like orifice, so that, as a rule, air cannot pass into it from the nose.

The *roof* of the nasal fossa is divided into three parts—viz. *nasal*, in front; *ethmoidal*, in the middle; and *sphenoidal*, behind; corresponding with the bones of the same name. The roof is at the front formed only by the conjunction of the septum and lateral walls, and is quite narrow, but it is broader near the choanæ. Above and behind the upper turbinal is a diverticulum of the nasal fossa, the *spheno-ethmoidal recess*, which communicates posteriorly with the sphenoidal sinus (fig. 293). The *floor* of the fossa is broader than the roof. In it in front is the incisor foramen, but this is in the recent state generally closed

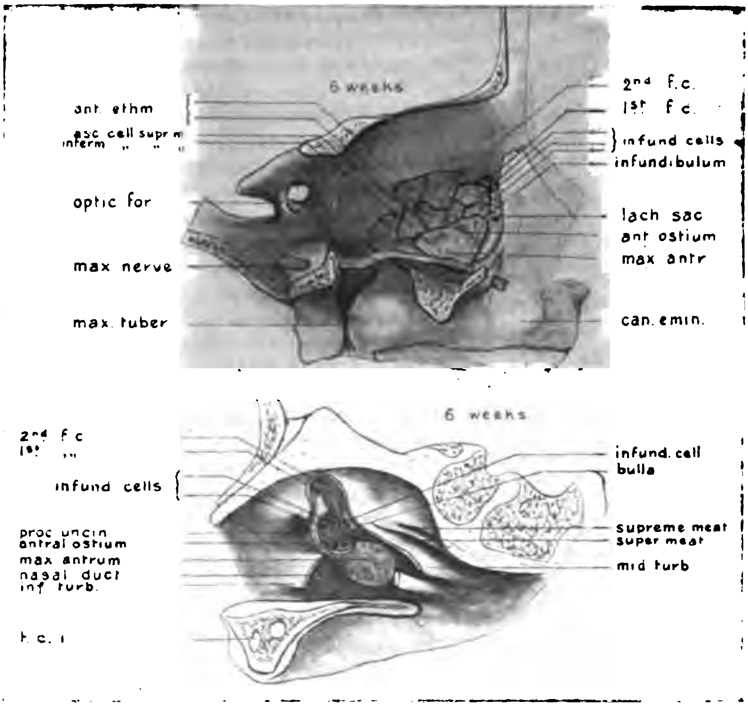
6 weeks
ant. ethm
asc. cell supr
interm ,, ,,
optic for
max nerve
max. tuber
2nd f.c.
1st f.c.
infund cells
infundibulum
lach sac
ant ostium
max antr
can. emin.
6 weeks
2nd f c
1st ,,
infund cells
proc uncin
antral ostium
max antrum
nasal duct
inf turb.
f. c. i
infund. cell
bulla
supreme meat
super meat
mid turb

Fig. 297.—The muco-periosteal walls of the accessory nasal sinuses exposed from the lateral and mesial aspects in an infant six weeks old. Natural size. (J. Symington.)

On the mesial aspect the middle turbinal was removed by dividing it near its attached border to expose the frontal recess, and the greater part of the uncinate process was taken away to show the infundibulum. By the removal of the middle part of the inferior turbinal the opening of the nasal duct and the extent of the nasal surface of the maxillary antrum are seen. (From a dissection by Dr. P. T. Crymble.)

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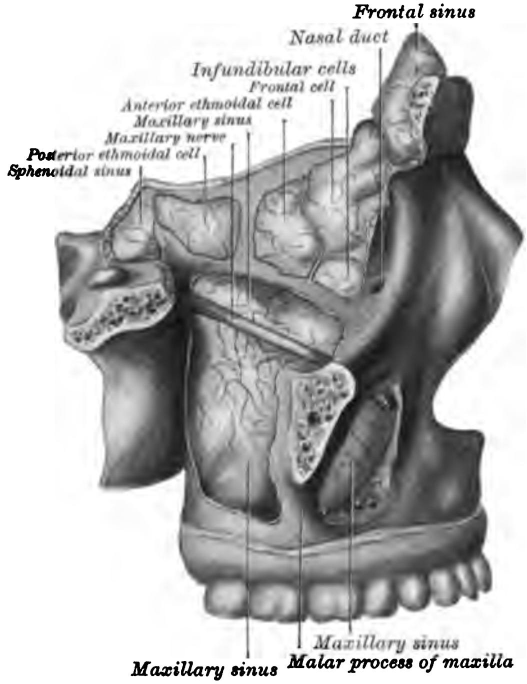
[1] For further particulars on this subject consult E. Zuckerkandl, Das periphere Geruchsorgan der Säugetiere, 1887; G. Killian, 'Zur Anatomie der Nase menschlicher Embryonen,' Arch. f. Laryngol u. Rhinol. ii., iii. and iv.; and Karl Peter, 'Entwickelung des Geruchsorgans in der Reihe der Wirbeltiere,' in Hertwig's Handbuch der Entwickelungslehre der Wirbeltiere, 1902.

(fig. 300). Sometimes, however, a narrow funnel-shaped tube of mucous membrane (*nasopalatine canal, canal of Stensen,* or *canalis incisivus*) passes obliquely downwards from each nasal fossa for a short distance towards the front of the hard palate. Vesalius, Stensen, and Santorini believed that these tubes of membrane opened generally into the roof of the mouth by small apertures close behind the central incisor teeth. Haller, Scarpa, and Jacobson found the canals in man usually closed, and often difficult of detection, and these statements have been confirmed by most modern investigators. The canal is a remnant of the wide communication between the nasal and buccal cavities found at an early period of fœtal life, being in man usually obliterated, at least in its lower part, before birth, although persistent in many animals. It long remains represented below by a solid column of epithelium-cells continuous with the epithelium of the palate, and above by a narrow tube lined with ciliated epithelium, opening into the floor of the nasal fossa, but closed below.



Frontal sinus
Nasal duct
Infundibular cells
Frontal cell
Anterior ethmoidal cell
Maxillary sinus
Maxillary nerve
Posterior ethmoidal cell
Sphenoidal sinus
Maxillary sinus
Malar process of maxilla
Maxillary sinus

FIG. 298. — VIEW OF THE LINING MEMBRANE OF THE AIR-SINUSES COMMUNICATING WITH THE NASAL CAVITY, EXPOSED FROM THE LATERAL ASPECT BY THE REMOVAL OF THE BONY WALL. (J. Symington.)

The part of the inferior meatus which lies behind the incisor canal, together with the space immediately behind the posterior end of the superior and middle turbinals as far back as the orifice of the Eustachian tube, belongs to the primitive buccal cavity of the fœtus, having become separated from the permanent mouth by the growth of the palate. It is known as the nasopharyngeal part (*ductus nasopharyngeus*), and its mucous membrane is marked off behind from that of the pharynx by a prominence which is termed the *nasopharyngeal fold.*

The anterior and lowermost part of the nasal cavity is termed the *vestibule* (fig. 292). This is bounded laterally by and corresponds in extent with the ala and the alar cartilage. It is lined by skin and is furnished with hairs and with sebaceous and sudoriferous glands. The hairs are large and numerous just within the orifice of the anterior nares (vibrissæ), but over the rest of the vestibule they are small and thinly scattered, and both the hairs and glands are absent near the posterior limit of the vestibule, which is marked off by a curved prominence (*limen nasi*), produced by the lower border of the lateral cartilage, from the nasal fossæ proper. At this line stratified epithelium of the vestibule passes into the ciliated epithelium of the fossæ, and the cutaneous glands are replaced by compound mucous glands. At the front of the vestibule, enclosed by the curved cartilage of the aperture, is a shallow *cul-de-sac* known as the *ventricle of the nares*.

Above and behind the vestibule, and in front of the turbinals, each nasal cavity appears on coronal section as a narrow vertical slit lined by mucous membrane covering the nasal bone above, the maxillary bone and its nasal process below and externally, and the cartilage of the septum internally.

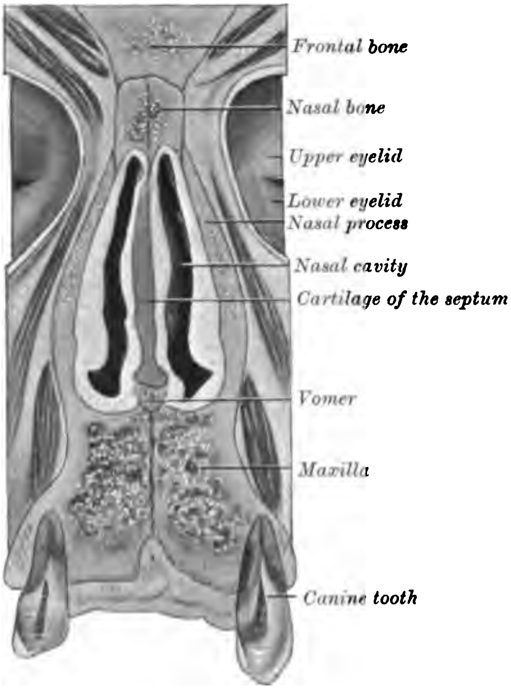


FIG. 299.—CORONAL SECTION THROUGH THE NASAL CAVITIES IN AN ADULT FEMALE BEHIND THE VESTIBULE AND IN FRONT OF THE TURBINALS, VIEWED FROM THE FRONT. Natural size. (J. Symington.)

MUCOUS MEMBRANE.

The pituitary or Schneiderian membrane, which lines the cavities of the nose, is a highly vascular mucous membrane, inseparably united with the periosteum and perichondrium over which it lies. It is continuous with the skin through the nostrils; with the mucous membrane of the pharynx through the posterior nares; with the conjunctiva through the nasal duct and lacrymal canaliculi; and with the lining membrane of the several sinuses which communicate with the nasal fossæ. The pituitary membrane, however, varies much in thickness and vascularity in different parts. It is thickest and most vascular over the turbinate bones (particularly the inferior), and on the septum nasi it is also very thick and spongy; but in the intervals between the turbinate bones, and over the floor of the nasal fossæ, it is considerably thinner. In the maxillary, frontal, and sphenoidal sinuses, and in the ethmoidal cells, the lining mucous membrane is very thin and pale, and contrasts strongly with that which lines the nasal fossæ.

The character of the epithelium varies in different parts, and by this, in a general way, three regions of the nasal fossæ may be distinguished. Thus, the region of the external nostrils (the vestibule) is lined with stratified squamous epithelium; and the remainder is divisible into two parts—viz. the upper or olfactory region in which the epithelium is non-ciliated and columnar, and the lower or respiratory region in which, as also in the sinuses, it is ciliated and columnar. The membrane in the respiratory part covers the middle and inferior turbinals and all the lower portions of the fossæ, and is studded with racemose glands, which open by orifices apparent on the surface. They are most numerous about the middle and hinder parts of the nasal fossæ, and are largest at the back of the septum near the floor of the nasal cavity. Glands which are much smaller and less numerous are stated to open into the several cavities which communicate with the nasal fossæ, but many observers have failed to find them. Besides the glands, the mucous membrane of the fossæ contains a variable amount of lymphoid tissue, occasionally accumulated into 'nodules.' In some parts large venous plexuses are found, encircled, as

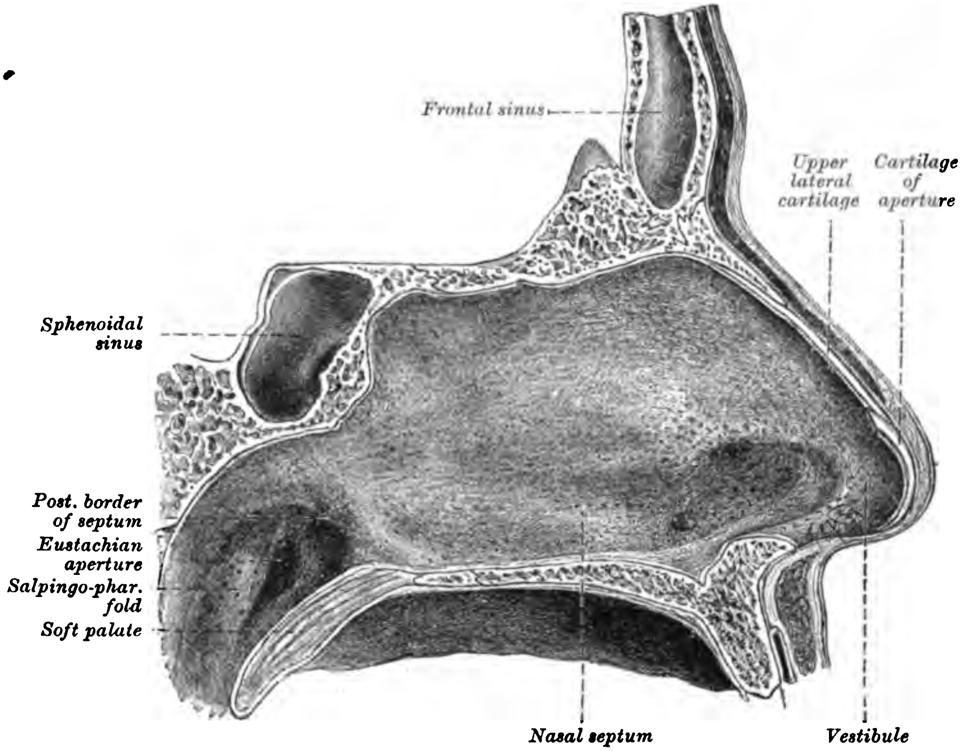


FIG. 300.—VIEW OF THE SEPTUM NASI FROM THE RIGHT SIDE. (Arnold.)

well as the alveoli of the glands among which they lie, by bundles of plain muscular fibres (Klein), thus forming a sort of cavernous tissue.

Olfactory mucous membrane.—The olfactory region, or that in which the olfactory nerve is distributed, includes in man only the uppermost part of the fossæ (superior turbinal and corresponding part of the septum, v. Brunn). It is extremely vascular, a close plexus of large capillary vessels being found under the lining membrane throughout its whole extent. Its mucous membrane is covered by a thick non-ciliated epithelium, more delicate in consistence than that of the ciliated region, being indeed soft and pulpy. It has a distinct yellow colour in man (*locus luteus*); brown in some animals; the colour may extend, however, beyond the true olfactory part of the mucous membrane. The glands of this region (*glands of Bowman*) are numerous, and are of a more simple structure than those in the lower part of the fossæ. They open by fine ducts lined with flattened cells which extend to the surface between the olfactory epithelium-cells (fig. 301). In the corium of the mucous membrane the gland-tube is convoluted and enlarged, and may have one or two branches. It is limited throughout by a basement-membrane, and lined and almost filled with columnar or polyhedral secreting cells. These are of the 'serous' type in man, but in some mammals there are 'mucous' cells intermingled with the serous (Paulsen). The gland-cells contain yellowish-brown pigment. In man the gland-ducts frequently open into a small sub-epithelial receptacle lined with flattened epithelium, from which a fine tube passes to the surface between the epithelium-cells. Occasionally the opening is into a ciliated crypt. Here and there the epithelium of this region, as shown by Max Schultze, is ciliated and not olfactory; where this is the case, the ordinary racemose glands are found (Klein). On the other hand, Bowman's glands are not entirely confined to the olfactory mucous membrane, but may extend a short distance beyond it into the respiratory part of the fossa.

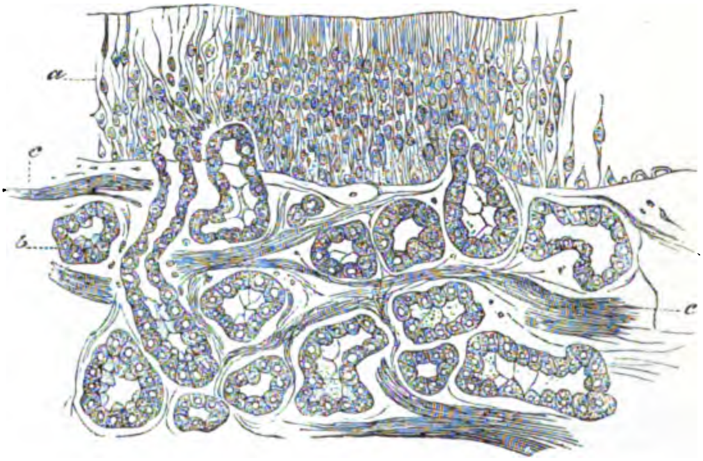


FIG. 301.—SECTION OF THE OLFACTORY MUCOUS MEMBRANE. (Cadiat.)
a, epithelium; *b*, glands of Bowman; *c*, nerve-bundles.

The columnar cells on the surface of the olfactory mucous membrane (fig. 302, *a*) are prolonged at their deep extremities into processes which are generally somewhat branched. The nuclei of these cells are oval in shape and lie all at about the same level (*zone of oval nuclei*)—*i.e.* in the deeper part of the columnar portion of each cell. The protoplasm of the columnar cells contains granules of yellowish-brown pigment. Among the branching central ends of these columnar cells there are a large number of peculiar spindle-shaped cells (fig. 302, *b*), each consisting of a large, clear, nearly spherical nucleus surrounded by a relatively small amount of granular protoplasm. From each cell proceeds a superficial and a deep process. The superficial process (*c*) is a cylindrical or slightly tapering thread passing directly to the surface, and terminating abruptly at about the same level as the free surface of the epithelial cells between which it lies, or a little beyond; the deep process (*d*) is more slender, and passes vertically inwards. This last usually presents a beaded appearance similar to that observed in fine nerve-filaments. These cells were termed by Max Schultze *olfactory cells*, to distinguish them from the columnar epithelial cells, which are much fewer in number, and which are entirely surrounded with the fine rod-like peripheral processes of the smaller cells. The nucleated bodies of the olfactory cells are several rows deep, and form a layer of considerable thickness beneath the columnar cells (*zone of round nuclei*).

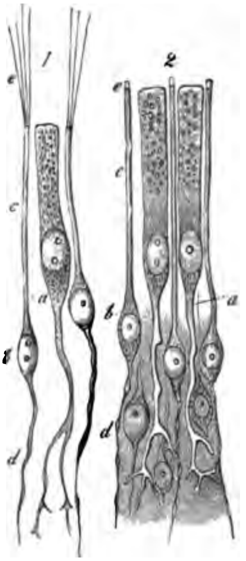


FIG. 302.—CELLS OF THE OLFACTORY REGION. Highly magnified. (M. Schultze.)

1, from the frog; 2, from man; *a*, epithelial cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral processes; *e*, their extremities, seen in 1 to be prolonged into fine hairs; *d*, their central filaments.

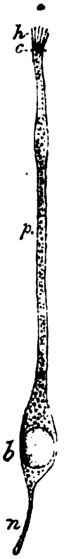


FIG. 303.—AN OLFACTORY CELL, HUMAN. (v. Brunn.)

n, central process prolonged as an olfactory nerve-fibril; *b*, body of cell with nucleus; *p*, peripheral process passing towards free surface; *c*, knob-like clear termination of peripheral process; *h*, bunch of olfactory hairs.

In the rabbit and guinea-pig (Klein, Sidky) there is a lowermost layer of conical vertical cells resting by their bases upon the membrana propria. Miss Read describes stellate cells in this situation in other animals and man.[1]

The total thickness of the olfactory epithelium in man is 0·06 mm., whereas in macrosmatic mammals it is 0·1 mm. or more (v. Brunn).

The olfactory (but not the columnar) cells extend through apertures in a cuticular lamina which bounds the mucous membrane superficially (*external*

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[1] American Journ. of Anatomy, viii. 1908.

limiting membrane, v. Brunn). The existence of this cuticle has, however, been called in question by other observers.

The peripheral process of the olfactory cell was observed by Schultze to be surmounted by a short projection (fig. 302, 2, *e*); according to v. Brunn, this appears in well-preserved specimens to be surmounted by a bunch of fine short hairlets, which are termed the *olfactory hairs* (fig. 303). Long and fine hair-like processes have long been known to exist on the olfactory cells of amphibia, reptiles, and birds (fig. 302, 1, *e*).

In amphibia and fishes the olfactory cells are grouped together in the form of bud-like organs resembling the taste-buds of the tongue.

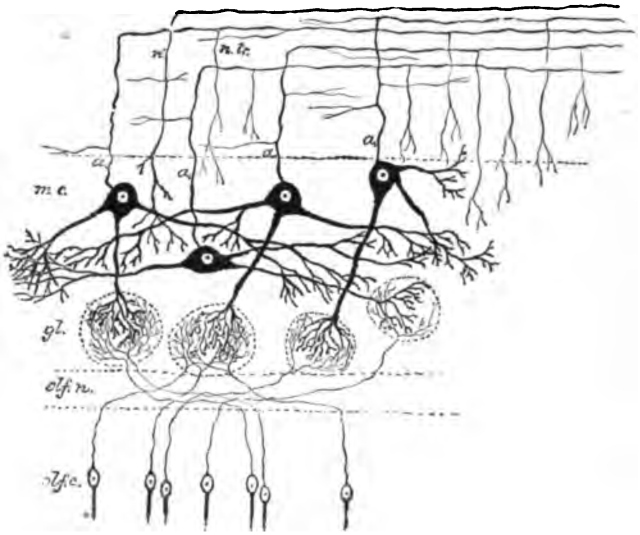

FIG. 304.—DIAGRAM OF THE CONNEXIONS OF CELLS AND FIBRES IN THE OLFACTORY BULB. (E. A. Schäfer.)

olf.c., cells of the olfactory mucous membrane; *olf.n.*, deepest layer of the bulb composed of the olfactory nerve-fibres, which are prolonged from the olfactory cells; *gl.*, olfactory glomeruli, containing arborisations of the olfactory nerve-fibres and of the dendrons of the mitral cells; *m.c.*, mitral cells; *a.*, their axis-cylinder processes passing towards the nerve-fibre layer, *n.tr.*, of the bulb to become continuous with fibres of the olfactory tract: these axis-cylinder processes are seen to give off collaterals, some of which pass again into the deeper layers of the bulb; *n'*, a nerve-fibre from the olfactory tract ramifying in the grey matter of the bulb.

It has been shown by various observers, by aid of the methylene-blue and silver-chromate methods, that the fine varicose central processes of these cells are directly continuous with the fibres of the olfactory nerve, and terminate centrally by dendritic ramifications in the glomeruli of the olfactory bulb (fig. 304). Neurofibrils are also observed within the olfactory cells.[1]

Olfactory nerve.—The filaments of this nerve, lodged at first in grooves on the surface of the bones, enter the substance of the Schneiderian membrane obliquely. The nerves of the septum are rather larger than those of the outer wall of the nasal fossæ; they extend over the uppermost part of the septum, becoming very indistinct as they descend. The nerves of the lateral wall are divided into two groups—the posterior being distributed over the surface of the upper turbinal, and the anterior over the anterior part of the olfactory groove.

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[1] W. Kolmer, Anat. Anz. xxx. 1907.

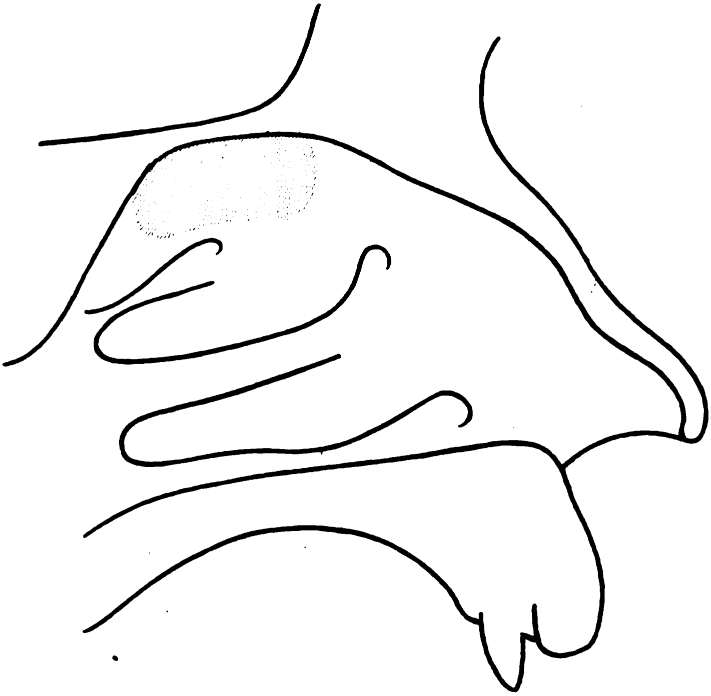

FIG. 305.—DIAGRAM TO SHOW THE EXTENT OF THE OLFACTORY EPITHELIUM ON THE LATERAL WALL OF THE NASAL FOSSA, AS DETERMINED BY MISS E. A. READ.

The part to which the olfactory epithelium is confined is coloured red.

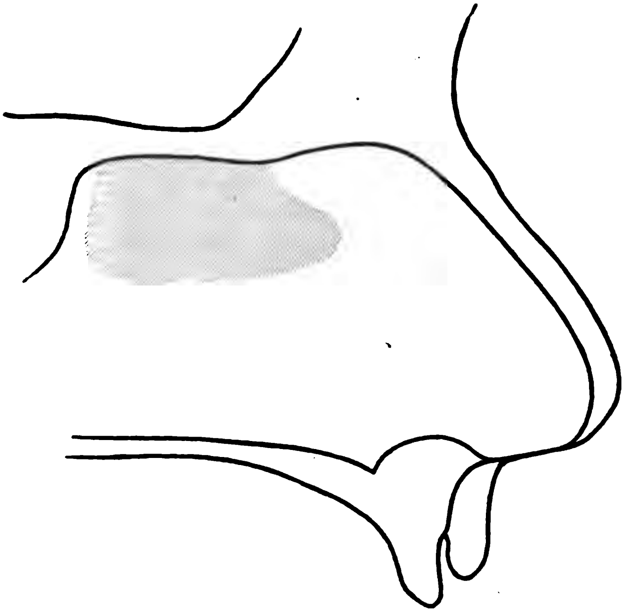

FIG. 306.—DIAGRAM TO SHOW THE EXTENT OF THE OLFACTORY EPITHELIUM ON THE SEPTUM NASI, AS DETERMINED BY MISS E. A. READ.

Many of the larger bundles are enclosed in grooves in the bone. In the embryo the extent of distribution of the olfactory nerves is relatively greater, but it becomes more limited as development proceeds, and ultimately the actual distribution of olfactory nerve-fibres, to judge by the character of the epithelium covering the membrane, becomes limited to a relatively small tract embracing less than the area of the superior turbinal and about one-third (or rather less) of the septum (figs. 305, 306). The nerves ramify so as to form flattened tufts. The nerve-bundles spread out laterally and interdigitate with similar offsets on each side to form what appears like a close plexus, with elongated meshes. But according to Miss Read there is no actual anastomosis between the nerve-bundles.[1]

In their structure the olfactory nerve-fibres differ much from the ordinary dark-bordered fibres of the cerebral and spinal nerves: they possess no medullary sheath, but are provided with a nucleated sheath, much more distinct than that of the fibres of Remak, and with fewer nuclei (fig. 307).

The greater part of the mucous membrane of the nasal fossæ is provided also with nerves of common sensibility, derived from branches of the fifth pair: the distribution of these has already been described. They end in arborisations among the epithelium-cells.

The organ of Jacobson.—In the anterior and lower part of the nasal septum a small aperture may sometimes be seen opening obliquely on to the surface of the mucous membrane slightly above and in front of the orifice of the nasopalatine canal (see fig. 300). This aperture leads into a minute canal which passes backwards for a short distance along the septum to terminate blindly a few millimetres from the orifice. The canal, which is lined with epithelium continuous with that of the nasal cavity and has numerous glands opening into it, is the homologue of a much more extensively developed tubular organ which opens in a similar position in many quadrupeds, and is encircled by a special curved plate of cartilage which lies below the septal cartilage on either side and is known as the cartilage of Jacobson. This is only represented in man by a narrow shred of cartilage (the vomerine cartilage of Huschke), which lies wholly below the rudimentary organ of Jacobson. In the rabbit and guinea-pig, as shown by Klein, and probably in other animals in which the organ is in a well-developed condition, the epithelium which lines the inner or mesial side of the canal is much thicker than that on the outer side. It is throughout similar in structure to that lining the olfactory part of the

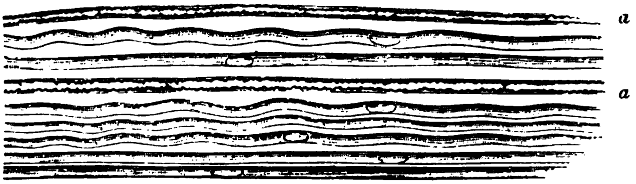

FIG. 307.—NERVE-FIBRES FROM THE OLFACTORY MUCOUS MEMBRANE. Magnified between 400 and 500 diameters. (Max Schultze.)

From a branch of the olfactory nerve of the sheep; at *a*, *a*, two dark-bordered or medullated fibres from the fifth pair, associated with the pale olfactory fibres.

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[1] Effie A. Read, American Journ. of Anatomy, viii. 1908. Miss Read describes a larger extent of distribution of the olfactory fibres in man than v. Brunn (Arch. f. mikr. Anat. xxxix. 1892), who limited the distribution to about one-half the areas shown in figs. 305, 306.

Schneiderian membrane. Moreover, it receives considerable branches of the olfactory nerve, and in these animals is no doubt of high functional importance as an accessory to the proper organ of smell. In man, the epithelium on the mesial wall of the canal is thick like the olfactory epithelium, but contains no true olfactory cells. Most of the cells are of the columnar (sustentacular) type, and although there are some more slender spindle-cells between these, probably homologous with the olfactory cells, they do not reach the surface, nor are they connected with nerve-fibres. Calcareous concretions are also frequent among the epithelium-cells, so that it is highly probable that the function of the organ in man is entirely in abeyance. In the embryo, up to eight weeks this epithelium is relatively far better developed, but after this time it appears to undergo retrograde changes.

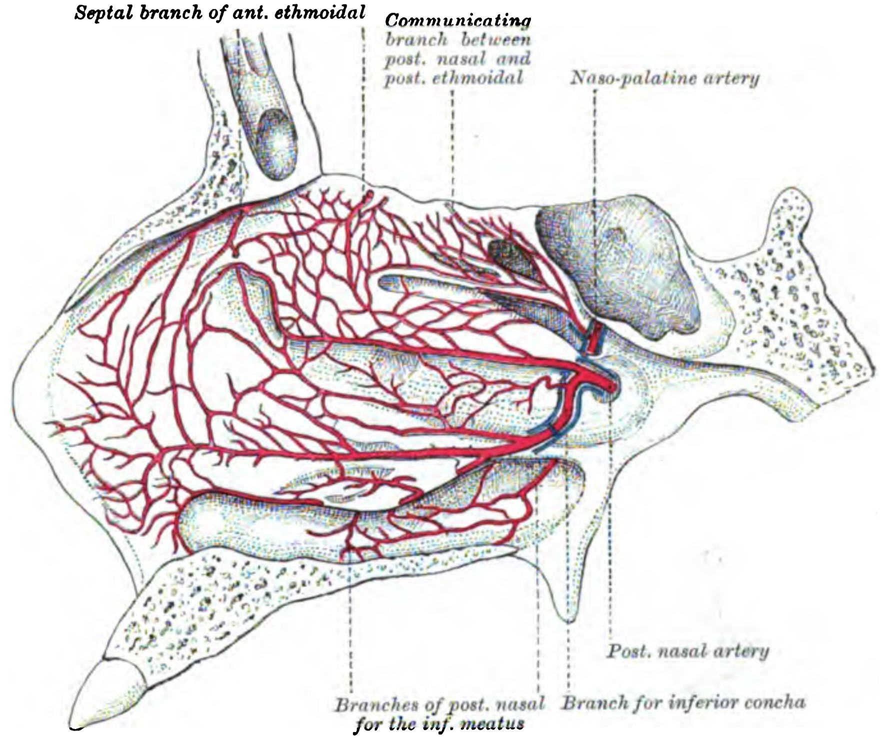
Septal branch of ant. ethmoidal
Communicating branch between post. nasal and post. ethmoidal
Naso-palatine artery
Post. nasal artery
Branches of post. nasal for the inf. meatus
Branch for inferior concha

FIG. 308.—ARTERIAL SUPPLY TO THE MUCOUS MEMBRANE OF THE LATERAL WALL OF THE NASAL FOSSA. (After Zuckerkandl.)

Blood-vessels and lymphatics of the nasal fossæ.—The *spheno-palatine branch of the internal maxillary artery* enters the cavity by the sphenopalatine foramen and divides into lateral branches (*posterior nasal*) to the meatuses and turbinals, sending offsets also to the ethmoidal cells and to the maxillary and frontal sinuses, and a mesial branch (*nasopalatine, artery of the septum*) along the septum to the incisor foramen. The branches of the spheno-palatine communicate freely with the anterior and posterior ethmoidal of the ophthalmic.

The *descending palatine branch of the internal maxillary artery* gives small offsets to the hinder part of the inferior turbinal and meatus.

The *anterior ethmoidal branch of the ophthalmic artery* enters the cavity with the nasociliary nerve and is distributed to the mucous membrane of the forepart of the septum and lateral wall.

The *posterior ethmoidal branch* of the same artery sends small twigs to the posterior ethmoidal cells, to the roof, and to the upper part of the septum.

Lastly, a *branch from the superior coronary of the facial* and the *lateral nasal artery* supply the part near the anterior nares. The several arteries anastomose freely together in the mucous membrane, and are distributed to three sets of capillaries—viz. a periosteal, glandular, and subepithelial.

The *veins* form a dense plexus in the mucous membrane, those in the deeper parts of the membrane being especially large and closely arranged so as almost to approach the structure of a cavernous tissue. This is most largely developed over the whole lower turbinal, the lower and hinder border of the middle turbinal, and the hinder end of the upper turbinal, as well as on the lower and hinder part of the septum. A similar dense venous plexus, continuous with that of the nasal fossæ, extends around the nasal duct, as far upwards as the lacrymal sac. The trunks leaving the cavity accompany the arteries, the *sphenopalatine vein* emptying itself into the pterygoid plexus; the *ethmoidal veins* joining the ophthalmic vein and the veins of the dura mater, and also sending a branch to join the veins of the orbital part of the frontal lobe of the brain (Zuckerkandl), and small veins passing out at the margin of the nares to join the venous plexus

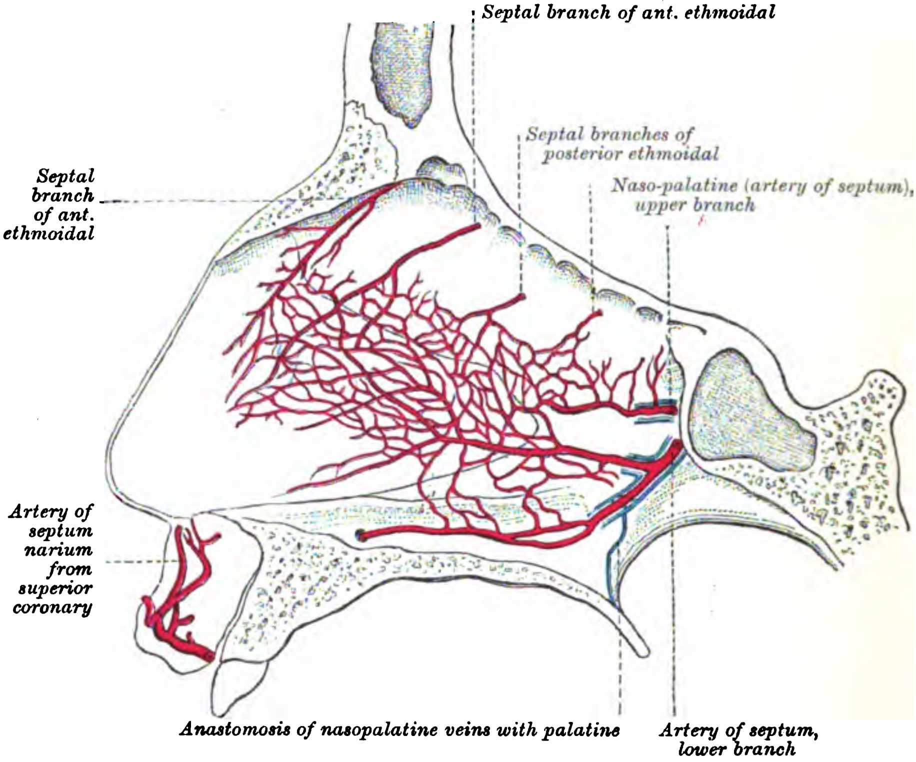
Septal branch of ant. ethmoidal
Septal branches of posterior ethmoidal
Naso-palatine (artery of septum), upper branch
Septal branch of ant. ethmoidal
Artery of septum narium from superior coronary
Anastomosis of nasopalatine veins with palatine
Artery of septum, lower branch

FIG. 309.—ARTERIAL SUPPLY TO THE SEPTUM NASI. (After Zuckerkandl.)

of the upper lip. Some small veins also pierce the nasal bone and the ascending process of the superior maxilla to join the commencement of the facial vein.

The *lymphatics* are abundant and large. They form a close plexus in the mucous membrane, the branches extending almost to the surface, and a more open plexus of valved vessels nearer the bone. These are in communication with the lymphatic spaces which enclose the branches of the olfactory nerve, and these spaces again communicate with the subdural and subarachnoid spaces of the cranium, so that the lymphatics of the nasal mucous membrane can be injected from the cranial cavity (Schwalbe, Key and Retzius). Lymphatic nodules are here and there present in the mucous membrane.

THE ORGANS OF TASTE.

The gustatory organs are represented by certain patches or groups of peculiarly modified epithelium-cells which are lodged in the thickness of the stratified epithelium of certain parts of the tongue and pharynx. These groups of cells have in mammals a bud-like arrangement, and have therefore been termed *taste-buds*. They occur at the sides of the circumvallate papillæ of the tongue (fig. 311), forming a zone around the papillæ, and (in man) upon the opposed wall of the vallum. They are also found on the fungiform papillæ of the back and sides of the tongue, extending to the tip, and here and there in the epithelium covering the general surface of the same parts of that organ. They are especially numerous over a small area just in front of the anterior pillar of the fauces (*fimbria linguæ*). This area usually displays four or five longitudinal folds or elevations

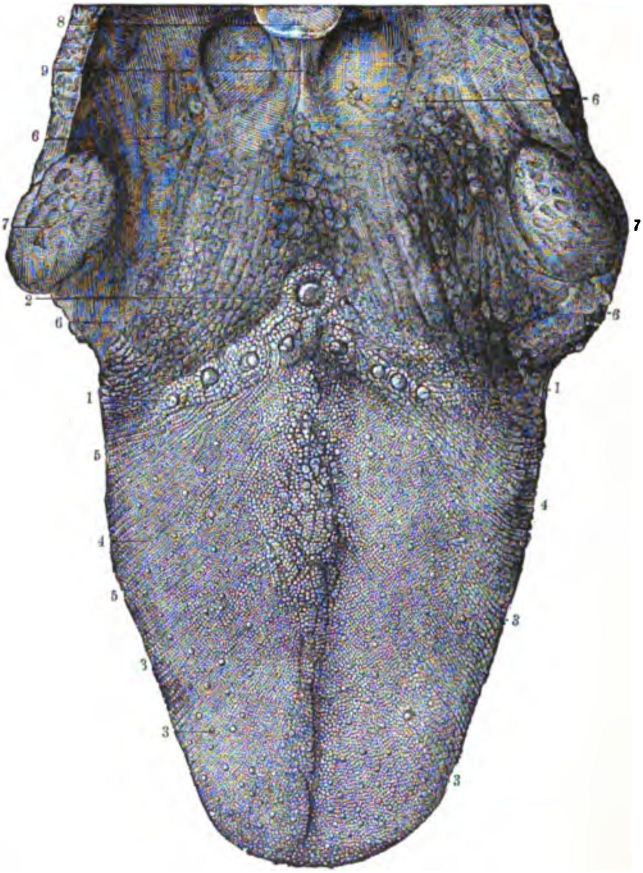

Fig. 310.—Papillary surface of the tongue, with the fauces and tonsils. (Sappey.)

1, 2, circumvallate papillæ; 3, fungiform papillæ; 4, 5, filiform and conical papillæ; 6, glands and glandular recesses; 7, tonsils; 8, tip of the epiglottis; 9, frænum epiglottidis.

of the mucous membrane, and appears to represent a much better defined oval laminated structure which is found in a similar situation in the tongue of the rabbit, and which is known as the *papilla foliata* (fig. 312). Taste-buds are also found over the anterior surface of the soft palate, and are very numerous over the posterior surface of the epiglottis. According to W. Krause they follow the distribution of the glossopharyngeal nerve.

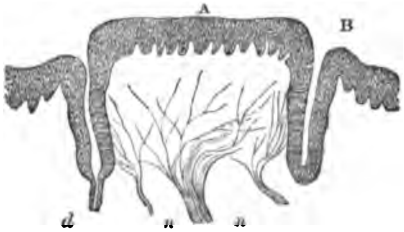

Fig. 311. — Vertical section of circumvallate papilla, from the calf. $\frac{25}{1}$. (Engelmann.)

A, papilla; B, vallum; *n*, bundles of nerve-fibres entering papilla; *d*, duct of a serous gland opening into fossa around papilla.

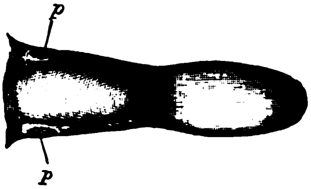

Fig. 312.—View from above of the rabbit's tongue showing the papillæ foliatæ. (E. A. Schäfer.)

Flask-shaped organs similar to taste-buds were discovered by Leydig in fishes in certain parts of the skin, and they also occur in the mucous membrane of the mouth and throat in those animals. In amphibia the taste-organs take the form of patches of modified epithelium-cells set on the surface of certain papillæ of the tongue. The structure of the taste-buds is most easily studied in sections of the papilla foliata of the rabbit (figs. 313, 314).

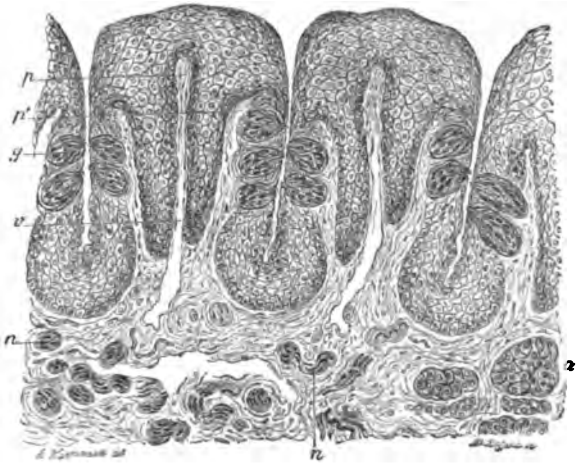

Fig. 313.—Vertical section of a foliate papilla of the rabbit, passing across the folia. (Ranvier.)

p, central lamina of folium; *v*, vein; *p'*, lateral lamina of folium; *g*, taste-bud; *n*, sections of nerve-bundles; *a*, serous gland.

Taste-buds have been compared in general form and appearance to the leaf-buds of a plant. They are flask-shaped bodies, the base of the flask resting upon the corium of the mucous membrane and the apex projecting towards the free surface of the epithelium, and emerging between the ordinary flattened surface-cells of the stratified epithelium. The cells of the stratified epithelium are adapted and applied to the outer surface of the taste-bud and form a sort of adventitious capsule for it. The most superficial cells may even be perforated to allow of the access of the apex of the taste-bud to the free surface. In any case the apex does not quite reach the surface, but is approached from the surface by a small opening, the *gustatory pore*. Into this a bunch of fine hairlets, prolonged from the gustatory cells of the taste-bud, is seen to project.

Every taste-bud contains two kinds of cells, termed respectively the *sustentacular* and the *gustatory* cells. The **sustentacular cells** (fig. 315, *c*) are long and spindle-shaped, tapering to either end. They form a complete envelope to the taste-bud, being fitted together like the staves of a barrel: these surface-cells are flattened from within out. Other sustentacular cells lie within the taste-bud among the gustatory cells, extending from apex to base of the taste-bud.

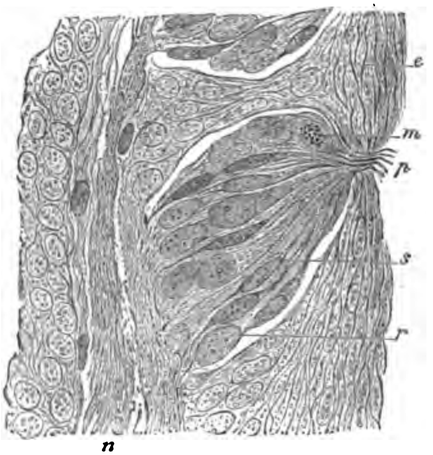

FIG. 314.—SECTION THROUGH ONE OF THE TASTE-BUDS OF THE PAPILLA FOLIATA OF THE RABBIT. Highly magnified. (Ranvier.)

p, gustatory pore; *s*, gustatory cell; *r*, sustentacular cell; *m*, leucocyte containing granules; *e*, superficial epithelium-cells; *n*, nerve-fibres.

The **gustatory cells** (fig. 315, *a*) closely resemble in general appearance the olfactory cells of Max Schultze (see p. 349). From the nucleated body of the cell, which is somewhat bulged, two processes extend. One, the peripheral, is nearly straight, and passes to the gustatory pore, where it ends in a cilium-like projection, the *taste-hair*. The other process, the central one, passes towards the base of the flask: it may be fine and varicose, and is often bifurcated or even further branched. According to G. Retzius and Lenhossék, it ends in a free extremity or extremities, and not, as was formerly thought, in continuity with the nerve-fibrils which pass to the taste-bud.

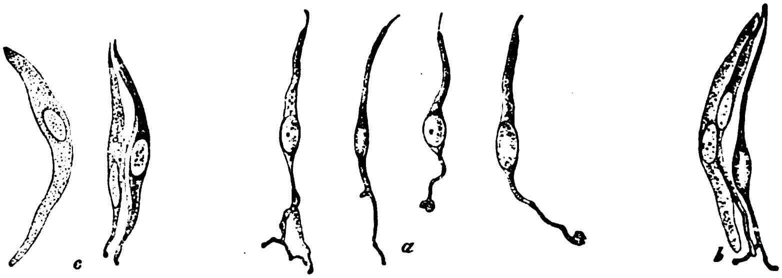

FIG. 315.—CELLS FROM TASTE-BUDS OF RABBIT. $\frac{600}{1}$. (Engelmann.)

a, four gustatory cells; *b*, two gustatory and one sustentacular cell; *c*, three sustentacular cells.

Each taste-bud receives a small bundle of nerve-fibres, derived, at least in the case of those of the circumvallate papillæ, from the glossopharyngeal nerve. The nerve-fibres lose their medullary sheath as they enter the organ and are continued as axis-cylinders, which end by ramifying amongst the gustatory cells (*intrabulbar ramification*, fig. 316, *i*). A number of nerve-fibrils also pass into the enclosing capsule of stratified epithelium and end by ramifying between the cells of that epithelium (*peribulbar ramification*, fig. 316, *p*). These peribulbar nerves are believed to be nerves of general sensibility, and not gustatory.

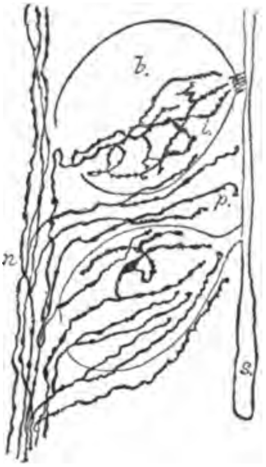

FIG. 316.—ENDING OF NERVE-FIBRES IN AND AROUND TASTE-BUDS OF RABBIT: Golgi preparation. (G. Retzius.)

Section of the glossopharyngeal nerves in young animals is followed after some time by atrophy of the taste-buds. The taste-buds of the anterior part of the tongue are supplied by the chorda tympani nerve.

COMPARISON OF THE MODES OF ARRANGEMENT OF SENSORY CELLS AND NERVE-FIBRES IN THE DIFFERENT ORGANS OF SPECIAL SENSE.

All the organs of special sense contain specially modified cells or the processes of such cells, the so-called nerve-epithelium cells or sense-epithelium cells, which serve to receive the physical impressions upon which the sensation depends, and to transmute these impressions into nerve-impulses, which are then conducted by nerve-fibres to a nerve-centre. The skin appears at first sight to present an exception to this general rule, but the ganglion-cells on the posterior roots, which send their peripheral processes in the form of nerve-fibres to end by ramifying in the skin, either in a special tactile organ or between the cells of the epidermis, do in fact represent the sense-epithelium cells such as we find in the olfactory organ and in the retina of the eye. This becomes plain from a comparison of the arrangements of the sensory nerves of annelids with those of vertebrates. Thus in the earthworm (Lumbricus) the whole epidermis is pervaded by cells (fig. 317, *s′*) which resemble in nearly every particular the olfactory cells of vertebrates. They are spindle-shaped cells, having two processes, one unbranched and extending straight to the free surface; the other branching and with one of its branches prolonged as a nerve-fibre to the central nervous system, there ending in a forked termination which comes into relation with branches of the nerve-cells of the centre. As in the olfactory organ, the sense-cells are supported by columnar epithelium-cells which are not connected with the nerve-centre. In other annelids (*e.g.* Nereis) the sense-cells are no longer situated between the other cells of the epidermis, but occupy a deeper position and send their peripheral process, which is still unbranched, to penetrate between the cells of the epidermis, and thus to reach the surface, whilst the central process is prolonged towards the central nervous system, where it terminates as in Lumbricus (fig. 318). Here, in Nereis, the body of the sense-cell, which, since it gives origin to a nerve-fibre or fibres, may be termed the sensory nerve-cell, is beginning to move away from the periphery. In Vertebrata, the only essential difference is that the same cell is farther removed from the periphery, and is nearer the central nervous system—viz. in the ganglion of the posterior root. In all vertebrate embryos and in some Vertebrata throughout life, the sensory nerve-cell is a spindle-shaped cell with a peripheral process extending as the sensory nerve-fibre towards the integument, and a central process, passing by the posterior root into the grey matter of the nerve-centre. In most Vertebrata, the spindle-shaped bipolar character of these sensory nerve-cells becomes lost, owing to the fact that as development proceeds the two processes shift towards one another at their attachment to the cell and ultimately come off from it by a common stem; but this is a mere secondary modification, and does not affect the validity of the comparison. In most other sense-organs the sensory cells remain at or near the periphery, and the most important differences between them consist in the relative extent of development of the centrally directed prolongation. In the auditory organ (fig. 319), which is an involuted portion of the integumental surface, the sense-cells are represented by the hair-cells of the maculæ and of the organ of Corti. Here a central process is absent, and the connexion with the central nervous system is effected by the endings of the auditory nerve enveloping the cell-bodies by a close terminal ramification. These hair-cells of the auditory organ are not in the same category of sensory cells with the olfactory cells of the nasal membrane or the visual cells of the retina. For they are destitute of a central or nerve-fibre process, and it may be doubted whether they transmute the auditory vibrations into nervous impulses. On the other hand, the manner in which the terminations of the auditory nerve-fibres surround or abut against the enlarged deeper ends of these cells suggests the possibility of a mechanical excitation of the nerve-terminations by a direct transmission of the vibrations of the endolymph through the cells in question. If this view be taken—viz. that the hair-cells of the auditory organ are not true nerve-epithelium cells, but only ordinary epithelium-cells somewhat modified for the transmission of mechanical impulses—then it will follow that the terminal sensory cells are to be looked for in the cells of the spiral ganglion of the cochlea and in the cells in the vestibular branch of the auditory nerve. These are bipolar cells having a peripheral process ending, as we have seen, in contact with the hair-cells, and a central process (auditory nerve-fibre) ramifying in the grey matter of the nerve-centre. There will thus be a close analogy, as regards nerve-ending, between the auditory and tactile organs. The gustatory organs belong to the same category as the auditory and tactile. It was formerly supposed that the central processes of the gustatory cells are prolonged into nerve-fibres, and these cells were therefore thought to correspond with the olfactory cells. But according to more recent observations the central process of the gustatory cell is not continuous with a fibre of the glossopharyngeal nerve, and the connexion of the gustatory cells with the fibres of that nerve is by contact and not by continuity. This being so, the arrangement in the gustatory organ is seen to be somewhat similar to that which obtains in the general integument and in the auditory organ (fig. 319).

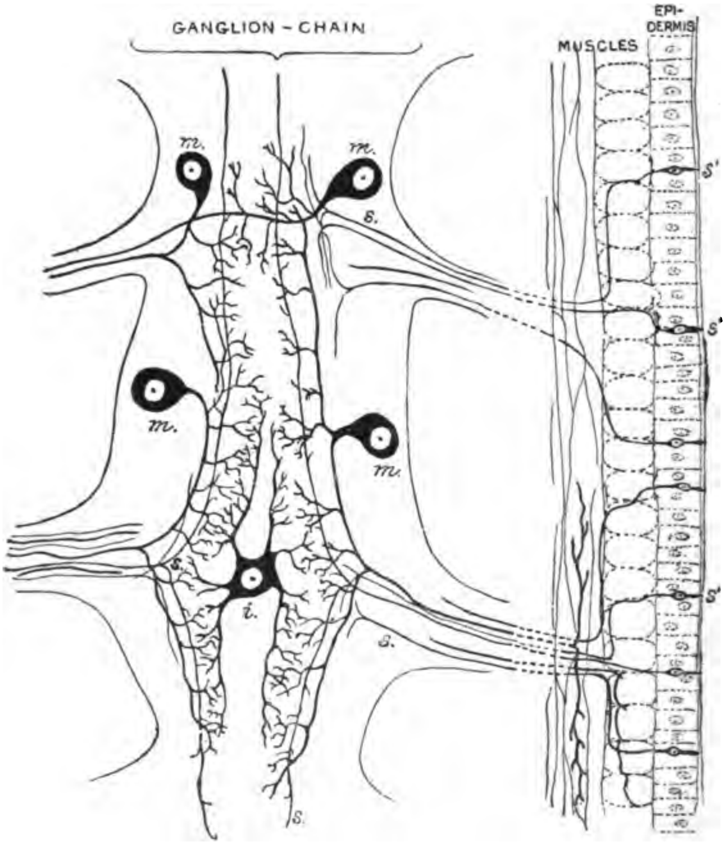

Fig. 317.—Diagram of the nervous system of the earthworm. (After Lenhossék and Retzius.)

m., motor cells; *s.*, sensory fibres emanating from *s'*, sensory cells in the epidermis; *i.*, median intercalated cell.

The retina of the eye, as its development shows, is rather to be regarded as an extension of the central nervous system than a peripheral organ. It is composed of nerve-elements (nerve-cells) which are arranged in three tiers (fig. 320). Those which are placed most peripherally are the visual cells or rod- and cone-cells, which resemble the general type of sensory cells in consisting of a nucleated enlargement or cell-body (outer granule) with a specially modified peripheral process (rod or cone), and a centrally directed ramified (nerve-fibre) process (rod- or cone-fibre). In the case of the cone-elements the peripheral process has been shown to be contractile, since it shortens under the excitation of light. It is

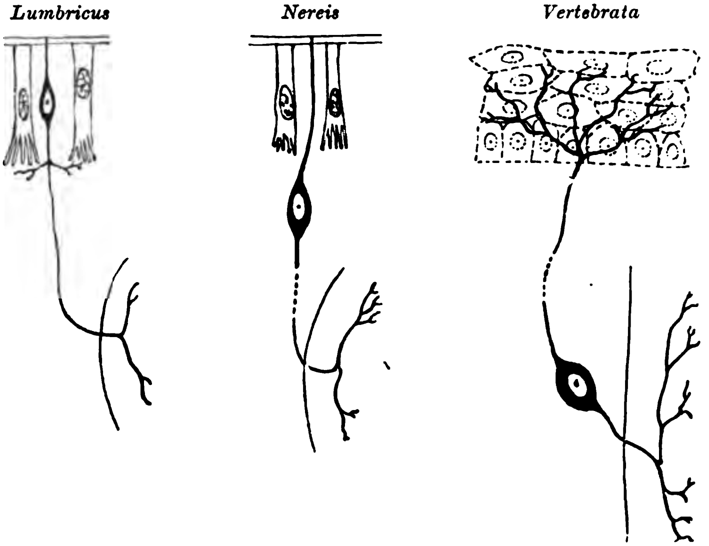
Lumbricus *Nereis* *Vertebrata*

FIG. 318.—DIAGRAMS SHOWING THE RELATIVE POSITION OF THE SENSORY CELL IN LUMBRICUS, NEREIS, AND VERTEBRATA. (After G. Retzius.)

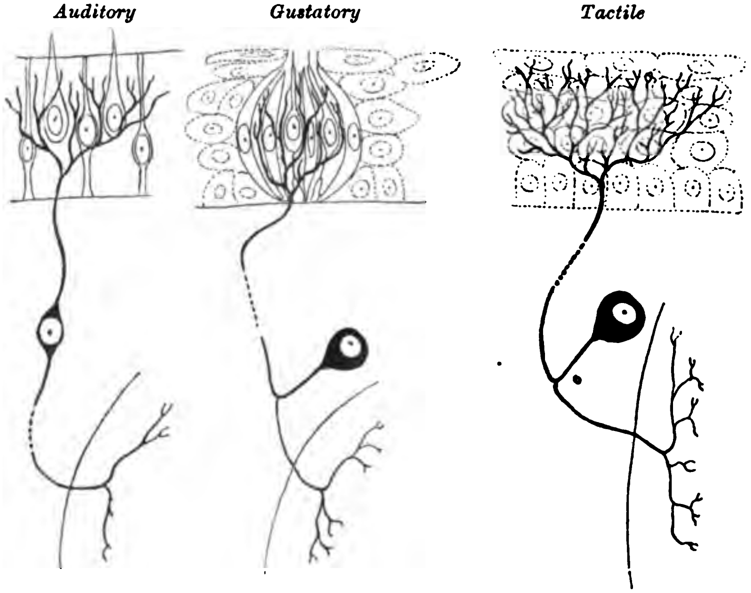
Auditory *Gustatory* *Tactile*

FIG. 319.—DIAGRAM SHOWING THE MODE OF TERMINATION OF SENSORY NERVE-FIBRES IN THE AUDITORY, GUSTATORY, AND TACTILE STRUCTURES OF VERTEBRATA. (After G. Retzius.)

usually believed that in these peripheral processes the nerve-impulses are produced and that the impulses are thence conducted centrally by the central or nerve-fibre process (rod- or cone-fibre), and by it transmitted to the next tier of cells. The second tier of nervous elements is formed by the layer of inner granules. Here there are bipolar nerve-cells, the peripheral processes of which interlace with the central processes of the rod- and cone-cells, but one peripheral fibre (fibre of Landolt) extends in most vertebrates beyond the rest and comes to lie between the bodies of the rod- and cone-cells. The central processes of the bipolars interlace with the peripheral processes of the cells of the next tier.

Lastly, the third tier of nervous elements is formed by the ganglion-cells of the retina, whose peripheral dendritic processes interlace with the central processes of the inner granules, and whose centrally directed processes are fibres of the optic nerve and have their central terminations in the grey matter of the general nerve-centres.

The comparison of the elements of the retina with those of the other sense-organs is not easy. If we compare the retina with the olfactory organ, we are at a loss to say whether we are to place the rod- and cone-cells along with the olfactory cells, as in making this comparison is most frequently done, or whether we should not rather look upon the bipolar inner granules as the homologues of those elements. In the latter case we should be led to suppose that the nervous impulses originate in the peripheral process of the inner granules, being there set up by a stimulation received from the rod- and cone-cells. And, although not probable, it is possible that this stimulation is a mechanical one caused by contraction of the rod- and cone-elements under the influence of light. If, on the other hand, we regard the rod- and cone-elements as representing the olfactory cells, there appears to be no structure in the olfactory apparatus homologous with the tier of bipolars of the retina. A comparison of the retina with the remaining sense-organs is also easier on the assumption that the bipolars represent the actual sensory cells in which nervous impulses originate in response to stimulation set up through the rod- and cone-elements.

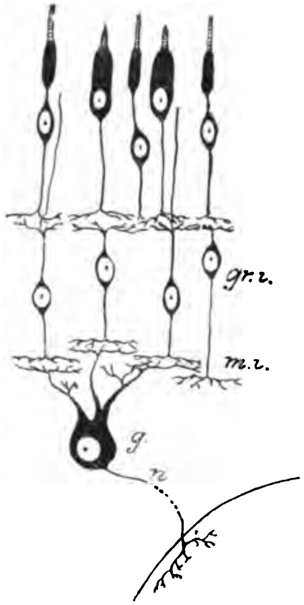

FIG. 320.—DIAGRAM OF THE CONNEXIONS OF THE RETINAL ELEMENTS. (After G. Retzius.)

gr.i., inner granules; *m.i.*, inner molecular layer; *g.*, ganglion-cell; *n.*, its nerve-fibre process or neuron ramifying in the nerve-centre.

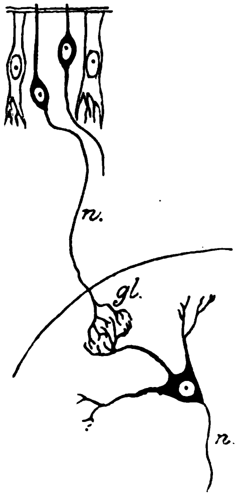

FIG. 321. — DIAGRAM OF THE ARRANGEMENT OF THE SENSORY NERVE-FIBRES IN THE OLFACTORY ORGAN AND BULB. (After G. Retzius.)

The connexions of the olfactory cells (fig. 321) more nearly resemble the primitive arrangement of sensory structures which occurs in Lumbricus than is the case in any other of the sense-organs. For here, as in the epidermis of Lumbricus, the sensory nerve-cells are at the free surface, lying between and supported by columnar epithelium-cells. And the sensory nerve-fibres are a direct prolongation of the fixed ends of the olfactory cells, passing to the nerve-centre and there becoming interlaced with the processes of the nerve-cells of the centre. The nature of the olfactory excitation, whether mechanical, chemical, or otherwise, is not known; but, whatever it be, we must assume that its result is to set up nervous impulses within the olfactory cells, and that these impulses are then propagated along the fibres of the olfactory nerve to the olfactory bulb: where, within the olfactory glomeruli, they are somehow transmitted to the dendritic processes of the mitral cells, through the nerve-fibre processes of which they are again passed on to other parts of the brain.

It will therefore be seen that all the sense-organs have this in common—viz. an originally bipolar sensory nerve-cell having (1) a peripheral process extending towards the surface and penetrating between more or less modified epithelium-cells which cover that surface, and (2) a central process which is in all cases recognisable as a nerve-fibre and the terminal ramification of which interlaces with ramifications of nerve-cells within a nerve-centre. The chief differences occur in the greater or less special modification of the epithelium-cells between which the peripheral processes penetrate, such modification being very considerable in the visual organ, less in the auditory and gustatory organs, very slight in the olfactory organ, and unrecognisable in the case of the general integument.

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